BIOLOGY

FITZPATRICK • HORTON

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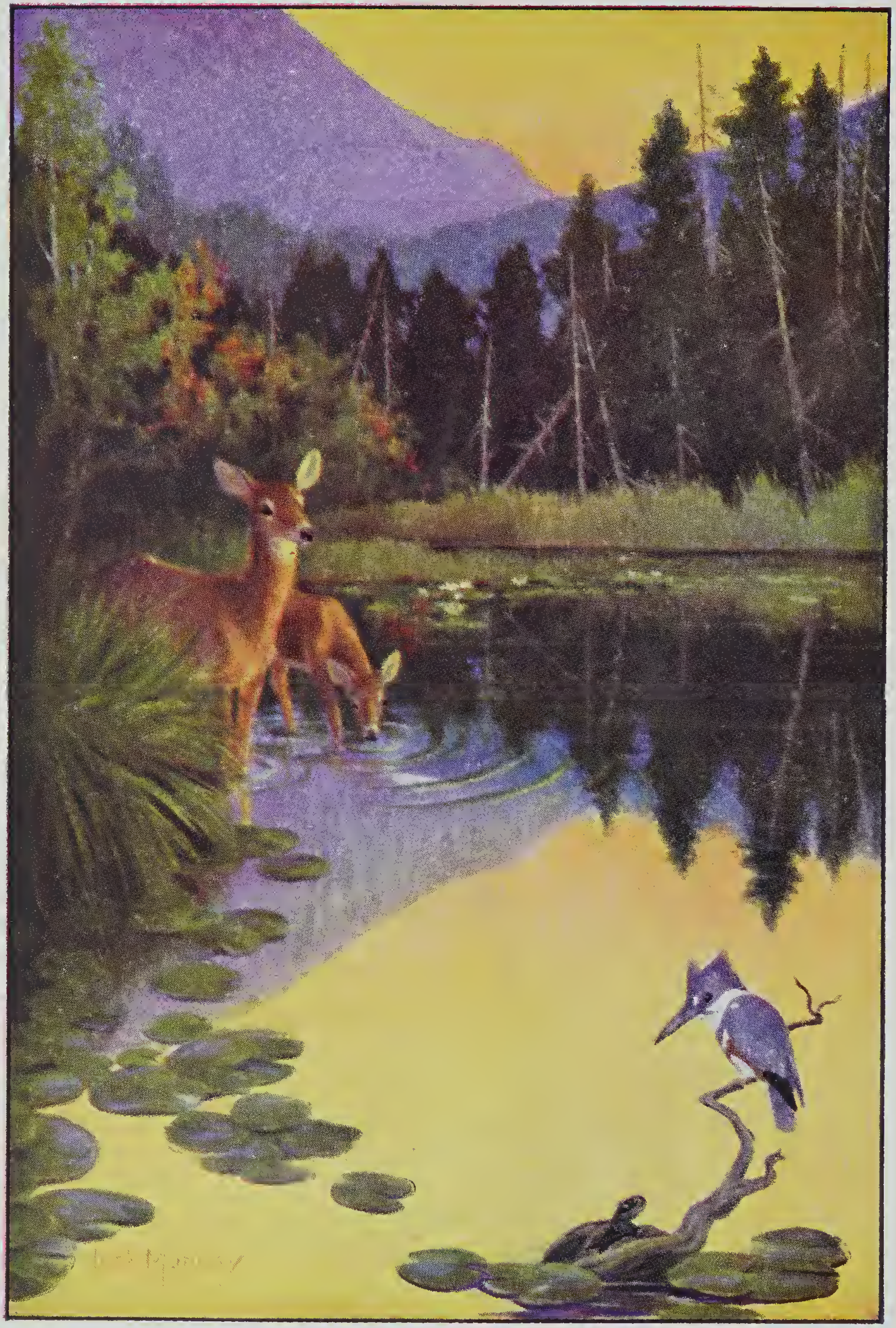

Early Morning

BIOLOGY

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PREFACE

BIOLOGY is the chemistry and physics of life. Through its study we come to know man, and the relationship of man to his environment. Such understanding has made us the dominant organisms of the world. It has enabled us to dwell in city or country with comparative security. It has had much to do with the production of adequate foods and other materials of commerce. In a word, biological knowledge has been of great practical value.

Thus the principles or concepts of biology have obvious and important application in everyday affairs. This textbook has been prepared in an effort to facilitate the understanding of such concepts. It provides a series of questions and a program of pupil activities for acquiring experiences that will be useful in solving common problems. At the same time, definite effort is made to give the pupil a knowledge of scientific methods, and to foster the development of scientific attitudes.

The foregoing trend in biological instruction was given impetus by the recommendations for a general biology course made in the Thirty-First Yearbook.[1] Early courses of study similar to the general pattern suggested were the *Tentative Syllabus in General Biology*,[2] and a course of study prepared by one of the authors.[3] Subsequently, additional recommendations concerning content have been made in *Science in General Education*.[4] These, and other proposals, focus attention upon biological materials that will enable the learner to gain familiarity with the things and forces of his environment and thus he will be able to deal with many problems of conduct in more intelligent fashion.

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[1] *A Program for Teaching Science; Thirty-First Yearbook, Part I.* National Society for the Study of Education, pp. 221–42 (E. R. Downing).

[2] *Tentative Syllabus in General Biology.* University of the State of New York, State Education Department, 1931.

[3] Fitzpatrick, F. L. *Biology for Public School Administrators.* Bureau of Publications, Teachers College, Columbia University, 1934.

[4] *Science in General Education*, Committee on the Function of Science in General Education, Progressive Education Association. Appleton-Century, 1938.

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The materials of the book have been arranged in seven units. Each *unit* deals with a specific, fundamental principle of biology. The *first unit* serves as a general introduction. It includes a discussion of the changing environment and the history of human progress in that environment. The *second unit* deals with the cell principle as exhibited by the structures of plants and animals. Physiology, considered as representing energy phenomena, is the subject of the *third unit.* Adaptations of function and structure are discussed in the *fourth unit.* The *fifth unit* deals with reproduction in plants and animals. This is followed by a *sixth unit* on variation and heredity. The *seventh unit* has as its subject the consideration of other organisms in relationship to human welfare.

Thus each unit provides student activities and experiences which relate to a basic concept or group of concepts in the field of biology. Throughout the book, also, certain unifying themes develop and become more meaningful with growing experience. These include:

1. The interrelationships of organisms.
2. Specialization and division of labor among cells.
3. The unity and the diversity of life.
4. Life as an energy phenomenon.
5. Adaptations of behavior and structure.
6. Biological control of undesirable organisms.

At the end of each chapter appear certain instructional guides. A number of Suggested Activities are indicated, from which teachers and pupils can select those which can best be carried out under existing conditions of work. There follows a Summary of Principles which have been developed by the discussions in the text. The Guide Questions point out the important facts to be learned, and can be used as a basis for class discussions. Certain books are listed under the heading Books to Read. Some of these are textbooks which may serve as books of reference in preparing reports, or in similar activities. Others are of a more popular nature, and may serve as general reading material. A Glossary of terms will be found at the end of the book. This instructional material has been developed as a result of the classroom experiences of a number of biology teachers. It includes the type of teaching devices that classes *need and use.*

The drawings which appear in the following pages were prepared by Mr. T. R. Miller. The colored plates are taken from oil paintings prepared for this text by Mr. Jack Murray.

The authors wish to express their indebtedness to a number of scientists who have read the manuscript and have given many valuable criticisms and suggestions. These include Dr. M. W. Jennison, Department of Biology, Massachusetts Institute of Technology; Professor D. E. Lancefield, Department of Biology, Queens College; Professor Edwin B. Matzke, Department of Botany, Columbia University; and Dr. Lloyd A. Rider, Chairman, Department of Biology, Abraham Lincoln High School, New York City. Portions of the manuscript dealing with materials from geology were read by Professor H. J. Arnold of Teachers College, Columbia University. The authors are also indebted to Director H. R. Dill of the State University of Iowa Museum for several photographs which appear in the following pages, to Dr. R. L. Ditmars of the New York Zoological Park for permission to reproduce three photographs, and to the New York Conservation Department for permission to reproduce two photographs.

TO THE PUPIL

Firsthand acquaintance with living plants and animals cannot be supplied by a book. On the other hand, the meaning of what we see about us in the living world remains a mystery to most of us unless we investigate by experiment or reading. Books are man's silent tutors. We cannot imagine a course in biology without living things to study and experiment with, neither is it economical of time or effort to try to learn without a book.

This textbook is designed to supplement observation and experiment in the field and in the laboratory. It describes situations which could not be brought into the classroom and it relates facts that have been gathered from all parts of the world. It contains explanations of your own experiences and those of other investigators so that the interrelation of all living things becomes clear.

If you propose to succeed in your course in biology we suggest the following methods of study:

1. Co-operate with your teacher who has planned the course so that you may learn the principles systematically.
2. Be sure you know each day just what the problem or topic is.
3. Observe closely the organisms or experiments which are provided for class study by the teacher or by the *Suggested Activities* in this textbook.
4. Make visits to the fields, woods, parks, seashore, or museums every week.
5. Notice the plants and animals in your home or in your daily surroundings.
6. Have a definite time and place for daily study of biology.
7. Read carefully the question or questions which are proposed for study. If one of the *problems* at the beginning of a chapter is proposed, *write* out this question on a piece of paper.
8. *Read the explanations and descriptions in the book* which refer

to this problem. Study the *pictures* and compare them with your own experiences. Use the *Glossary* to master precise meanings of words. Write brief notes of important ideas that occur to you as you read.

9. Try to answer the *Guide Questions* at the end of the chapter. If you cannot answer them, find the paragraphs in the book which refer to the items and read the explanation again.
10. Read carefully the *Summary of Principles*. Try to recall an *example* of each principle stated.
11. Finally, reread the problem of the day's lesson. Can you now give a clear explanation of the problem, with facts and examples to illustrate the principles?
12. Be orderly, systematic, and thoughtful about all your work.
13. Talk with your friends about your work. Challenge assertions that are not supported by facts.
14. Undertake one of the *Suggested Activities* as an investigation of your own. Try to become "scientific."

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UNIT I

THE CHANGING ENVIRONMENT

TO UNDERTAKE the study of biology is like starting upon an adventure. An explorer like Admiral Byrd or Roy Chapman Andrews makes careful plans as to just where he is going. He studies maps, and charts his course. He plans his trip, and finds out in advance the kind of country he is about to enter. In beginning our study of biology, we should in a similar manner survey the field, and plan our course.

Most students of biology are only continuing the study of science begun long before they reached high school. It is to be expected that experiences gained in elementary science, and observations of the world about us, will be helpful in the further study of science. Probably you do not need to be told that biology has to do with animals and plants. Almost certainly you have learned something about the methods used by scientists in their work. This new study should give you a better understanding of both of these matters: namely, biology, and scientific methods. These are the primary purposes of the course: (1) to gain a better understanding of the processes which govern affairs in the living world, and (2) to improve our abilities in the use of scientific methods of thinking and acting.

This first unit proposes to survey the field we are going to explore. What are the "problems" of living things? How many kinds of living things are there? Where do they live, and how do they manage to get along in a world that is changing all of the time? For we shall learn that the surroundings of a plant or an animal change continually. Sometimes these changes are slight and are of no great importance. Other changes, however, affect the well-being of plants and animals very greatly.

In other words, we propose to study the world and its living inhabitants. Among these inhabitants we ourselves must be included. Is the welfare of man related in any way to the presence or absence of other living things? It is sometimes said that man is learning to control the conditions under which he lives. In what ways is this being done? How has man made progress in civilization?

In this study of life and its surroundings, we shall discover many new questions about living things. We shall use these questions to direct future studies. Like explorers, we shall attempt to plan our "journey" in the study of biology.

CHAPTER I

LIVING THINGS AND THEIR ENVIRONMENT

Problems:

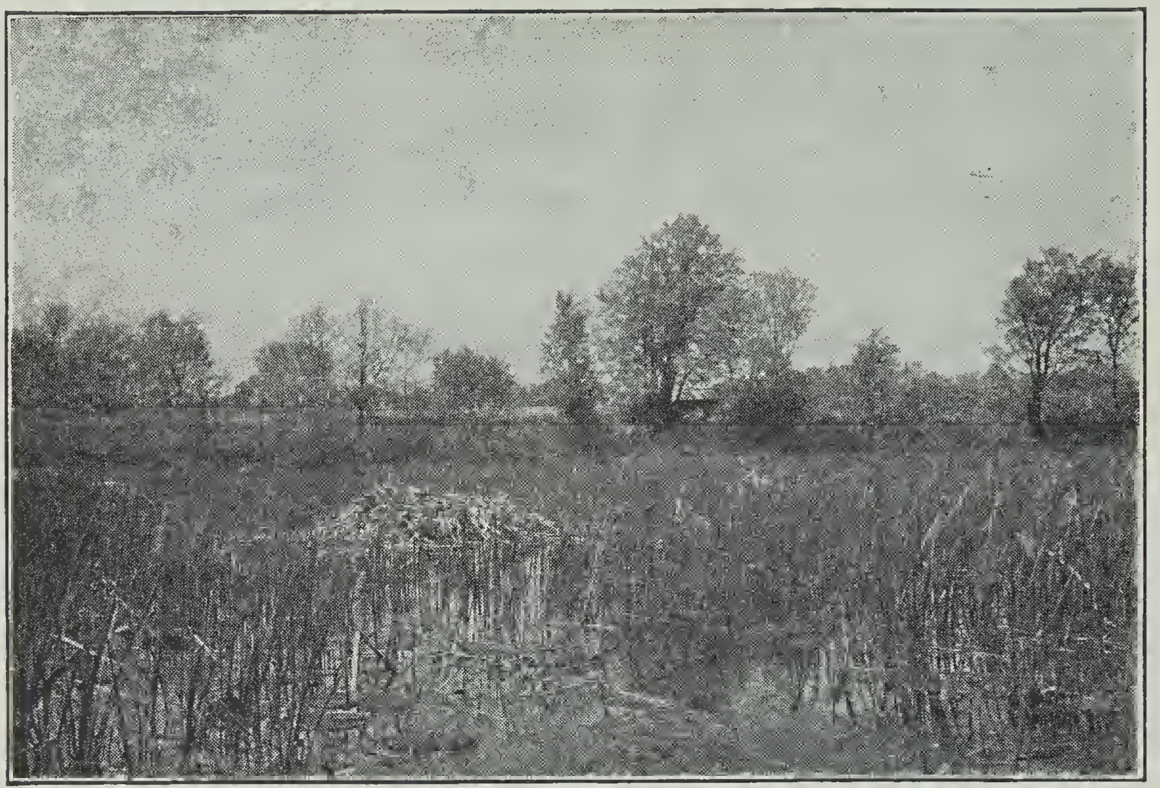
1. What is the nature of an "environment"?
2. How numerous and varied are plants and animals?

AN ENVIRONMENT INCLUDES MANY FACTORS

Foreword. Have you ever looked at a pond or stream and wondered what fish might lie hidden there? Have you walked through the forest and noticed the many types of plants, the birds and other animals? In such places as these we are able to find answers to some important questions of biology. We may learn many things about the growth of plants. We may see some of the ways in which plants and animals obtain their food. We may discover how many living things avoid destruction by their enemies.

Not all of our biology laboratories are under roofs. If we wish to know how living things are related to each other in a state of nature, we must see them in natural settings. Thus the marshes, streams, and forests become our classrooms and laboratories. Let us begin our study by visiting a fresh-water pond, and studying one of its inhabitants — a leopard frog.

A fresh-water pond. Such a pond often has banks that slope down gradually to the water's edge. There usually is an area of muddy shore. A veritable wall of cattails may grow along parts of the shore or in the shallow water. A short distance back from the water grasses, bushes, and other plants often form a fringe which encircles the pond. Here and there some bushes hang down into the water. Lily pads will be seen spread out upon the surface of the pond. No doubt some small stream discharges water into the pond. Possibly another stream acts as an outlet when the pond overflows. During prolonged dry weather the water level of the pond may be very low.



American Museum of Natural History, New York.

FIGURE 1. A fresh-water pond. Describe a "food chain" that might be found here.

If we are conducting our study during the autumn, we shall probably find that the water is warm and somewhat muddy. The tracks of birds, muskrats, rabbits, and even minks or raccoons may be found in the mud at the water's edge. These tracks indicate that these animals have come to this place in search of food or to obtain water.

If muskrats are in the vicinity, they may have constructed one or more muskrat houses in the shallow water at some distance from the shore. Or their tracks may lead to holes which enter the banks at or below the water level. We may find that they have worn trails in the mud and grasses in going back and forth between the pond and the surrounding marsh.

Insects will be seen upon the grasses and other plants that grow near by. Some of them will be observed flying about, and some types, such as the pond skaters, may be seen upon the surface of the water.

If we are especially observant we may see three or four turtles

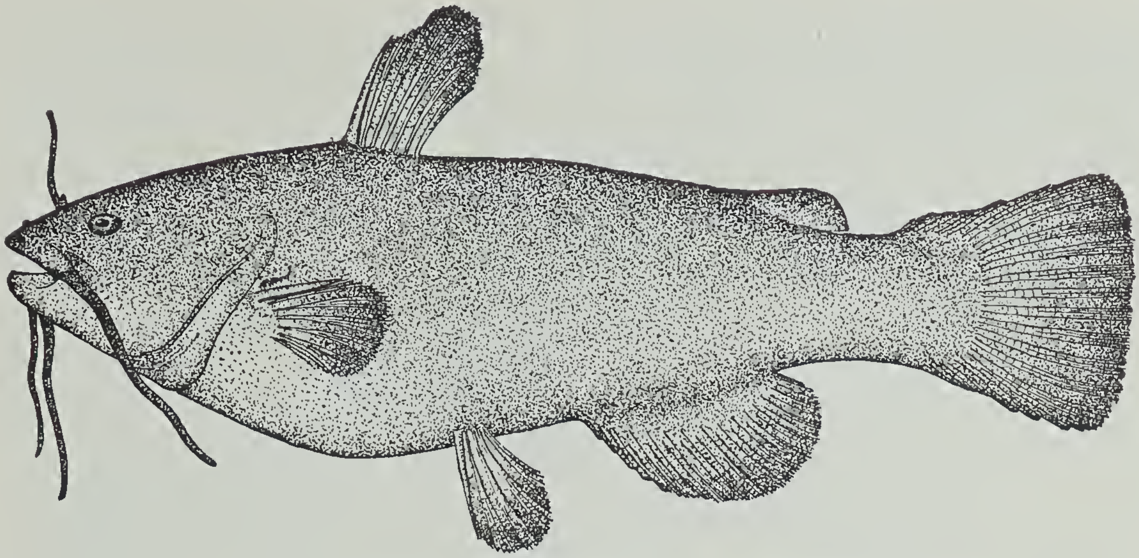


FIGURE 2. A catfish; an example of a fresh-water animal.

that have been basking in the autumn sun upon a floating log. When they become aware of our approach they will drop off into the water and we shall probably not see them again. Perhaps a snake may be seen crawling across the beach or swimming across the pond. No doubt this snake will be alarmed by our approach and will try to avoid us.

We may note a splashing of the water as a fish rises to the surface and captures a floating insect. A kingfisher may appear overhead, suddenly dive down into the water to seize a small fish, and then fly away with its victim.

It is in such a situation as this that we may expect to find a frog. We may see this animal sitting upon the muddy shores of the pond, or upon a floating stick, or upon a lily pad at some distance from the shore. Why does a frog live in such surroundings? What are some of the important factors in the life of a frog?

In the first place, the adult frog has developed from an egg that was deposited in the water by a female frog, perhaps in this same pond. When the egg developed, a tadpole was produced, and this tadpole lived in the water for a period of time. Finally the latter developed lungs and limbs, and came out upon the beach as an adult frog. Being possessed of lungs, the frog was able to breathe air, and was no longer confined to the water.

One of the "problems" of a leopard frog is to obtain food. The adult frog is an animal that feeds largely upon insects and worms. Most of these insects and worms are found near the shores of the pond. The insects may live on or among the plants that grow near the water. These plants, which furnish food for many of the insects, and hiding places for others, are of importance in the life of a frog. The presence of the plants, in turn, is dependent upon a number of factors. These factors include the presence and nature of the soil, the presence of moisture, favorable temperatures, and sunlight. Therefore, these factors indirectly affect the life and well-being of a frog.

If we consider another phase in the life of a leopard frog, we shall find that a number of its activities are directed toward escape from its enemies. One type of animal frequently found in and about fresh-water ponds is a water snake. Water snakes feed upon frogs. If a frog is resting or seeking food upon the shores of the pond, it may be captured and eaten by one of these snakes. When a frog takes to the water it may be devoured by a fish or some other large enemy.

Water snakes and fish do not feed only upon frogs. Other living things must be present if the snakes are to exist. Furthermore, certain physical conditions of temperature, pressure, and the like, are necessary circumstances in their lives. We see, then, that all of the factors which make possible the presence of water snakes and fish are likely to affect in turn the life of a frog.

There is also another phase of this problem. Some of the fish that eat frogs are in turn attacked by other living things. Man, for instance, may catch them. Or the blood-sucking leeches that are sometimes found in the water may attach themselves to fish, suck their blood, and so destroy them. There are also many small, parasitic worms which may gain entrance to the bodies of fish, and sooner or later cause the death of the latter. Water snakes also have their natural enemies who seek to destroy them. Again it will be seen that all agencies which tend to destroy water snakes and fish, including natural enemies and unfavorable physical surroundings, may have an indirect effect upon the life of a frog.

Ewing Galloway, New York.

FIGURE 3. One type of environment — the shore of a tropical island.

All of the factors that have been mentioned, and many, many others, combine to make up the environment of a frog. For environment refers to the surroundings of an animal or plant. Environment refers both to things and conditions. No object or condition is too small or slight to be considered a part of the environment of any living thing.

We recognize that the environment of a living thing may include air, water, soil, pressure, temperature, food, light, natural enemies, plants and animals that are not natural enemies, and many other factors as well.

In the country the environment includes trees, wild birds, fields of grain or vegetables, meadows, ponds, rivers, domesticated animals, clean air, and similar factors that we associate commonly with rural life. In the large city the environment includes the skyscrapers, pavements, parks, stores, subways, crowds of people, dusty air, and the noises of the streets.

THERE ARE MANY DIFFERENT KINDS OF LIVING THINGS

In our study of the leopard frog a number of living things, many of them familiar objects, have been mentioned. When we visit a locality such as the shore of a fresh-water pond, we expect to see many living objects. These include trees, other large plants, mosses, ferns, birds, frogs, some insects, and perhaps snakes, fishes, rabbits, squirrels, and muskrats.

Species. To be sure, many different kinds or species of plants and animals may be included in the foregoing group. The trees, for instance, may include various kinds of willows, ashes, oaks, maples, poplars, birches, and elms. But except in the case of the trained observer, a variety of types may pass unnoticed.

Among the less conspicuous plants many species of grasses and the tiny algæ may not be recognized. As for both animals and plants, dozens of types may not be seen because they are too small, or because they are hidden from view.

Suppose, for instance, we were to break up a tree trunk or stump that is lying partly buried in the soil and is decaying. In many cases we should find that the decaying wood concealed several kinds of insects. In some cases we might discover that earthworms had worked up into the decaying wood from the soil beneath. Several species of earthworms might be found, and other small animals might well be present. In addition, a microscopic examination would probably indicate the presence of certain tiny, simple plants known as bacteria. As to the external surface of such a log or stump, we might find various species of mosses, lichens, and mushrooms growing upon it.

If we turn over fallen leaves or branches, we are likely to find similar forms of life beneath them. Even the soil is inhabited by insects, bacteria, earthworms, moles, gophers, some species of mice, and many other living things.

Masses of greenish or brownish material may be seen floating upon the surface of the pond. Often this material is called "green scum." It is composed of many small plants known as algæ. They are among the simplest of plants, and some of them live as separate, single cells, while others live as groups of cells or colonies.

When we obtain some water, including some decaying plants, from a shallow place near the shore, and examine this material with the aid of the microscope, we begin to appreciate how many kinds of living things really are present in such a locality. Here again we may find many bacteria if our microscope is of the proper type. There may also be many different algæ. There are, too, likely to be numerous representatives of the simplest group of animals, the protozoa. These may be seen by the unskilled observer more readily than some other forms, such as the bacteria. Other animals may include such types as snails, clams, many kinds of worms, water-dwelling insects, or insects which pass the early stages of their development in the water. Even leeches and small representatives of the group of animals known as crustaceans may be present. It is quite possible that a quart jar of such material might contain thousands of individuals representing many species.

When we visit the seashore we learn that many plants and animals are to be found in or about the water. We see great masses of seaweed thrown upon the beach — these are water-dwelling plants. As the tide goes out, we may find clams, crabs, sea urchins, starfishes, and other forms of life. The waves wash up the skeletons of dead animals that ordinarily are not found in the shallower waters. While we are bathing, our skin may smart from contact with the stinging cells of a jellyfish, and we may encounter masses of algæ and the floating eggs of animals.

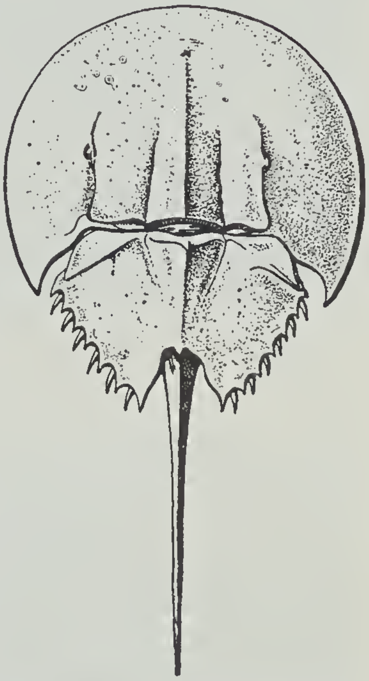


FIGURE 4. A king crab; an animal which lives in the sea.

The more we come to know and understand our environment, whether it be the seashore, the inland fields and pastures, or the mountains, the more we appreciate the fact that living things are of many different kinds and are very numerous. If we live in the tropics, we are likely to be impressed with this fact very early in our experience. Here the warmer climate favors the

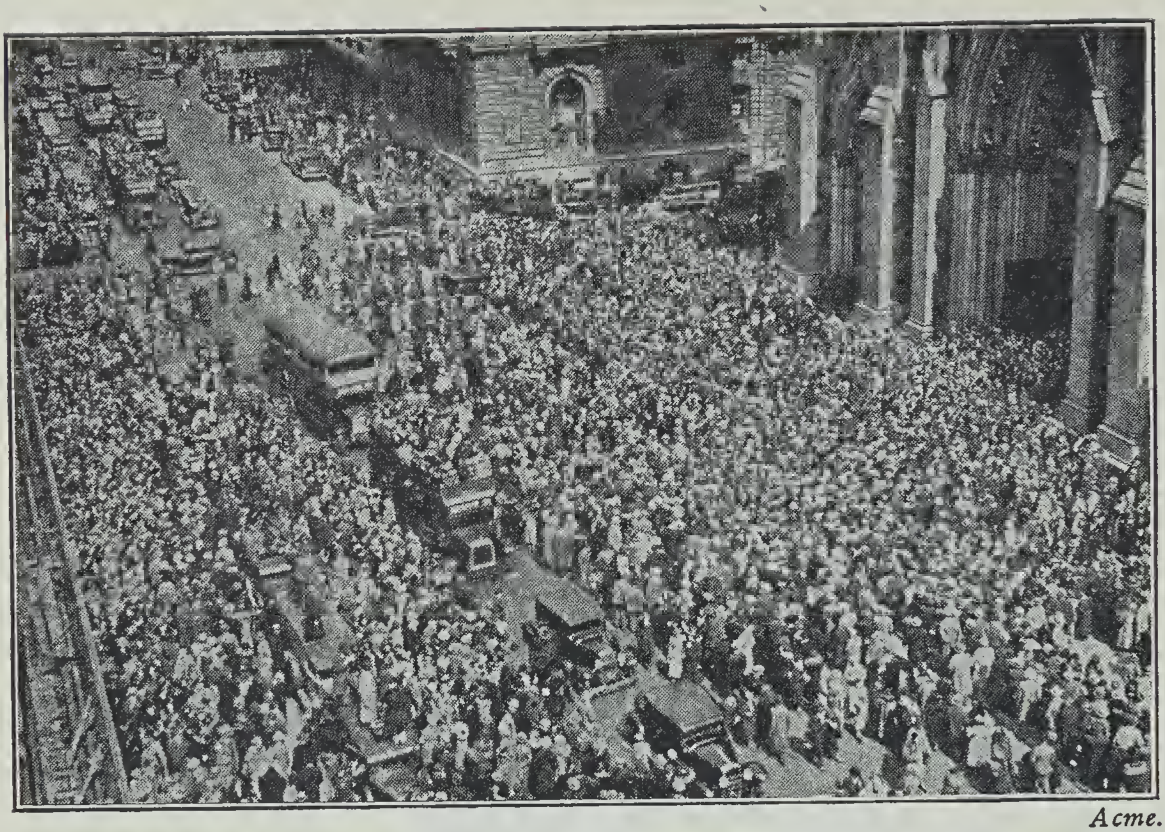


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FIGURE 5. Crowded city streets. The environment of some human beings.

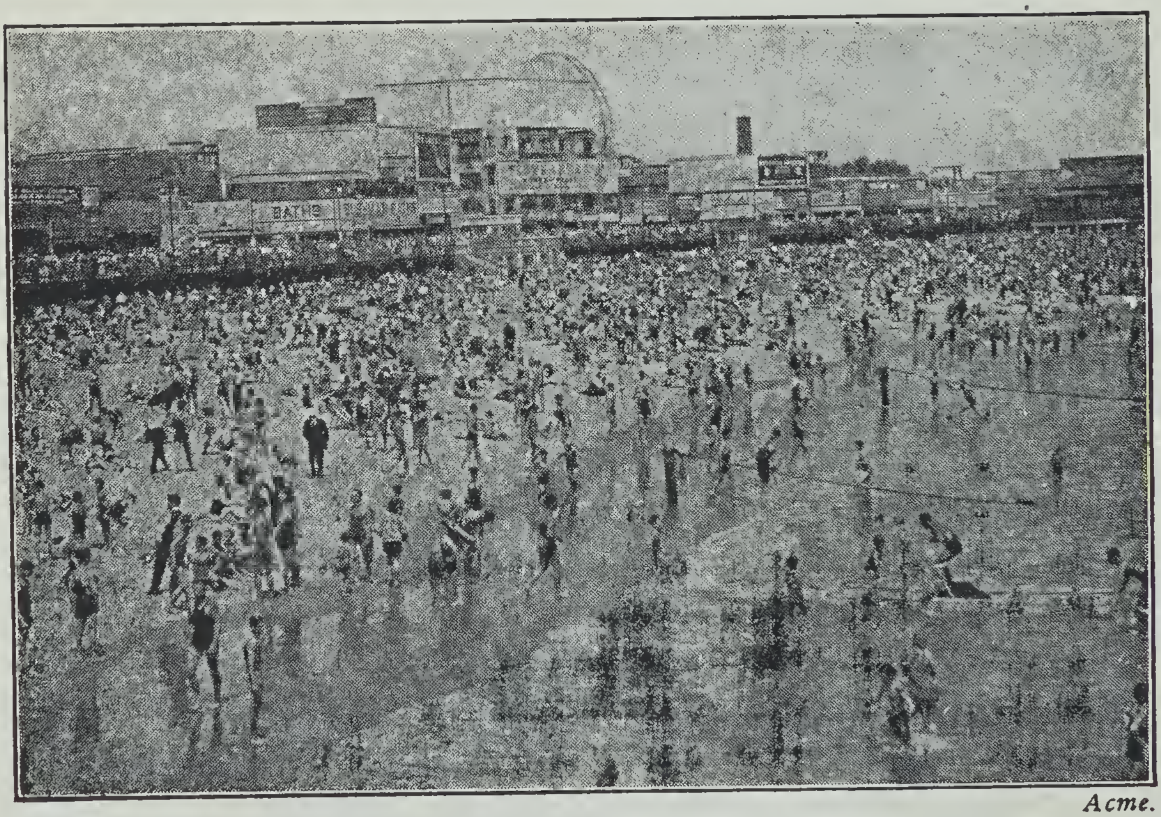

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FIGURE 6. A crowded sea beach. What factors attract people to this environment?

rapid increase of insects and many other animals, and vegetation grows with amazing rapidity. Even in arctic regions many forms of life are represented. There, to be sure, the species are largely different from those found in tropical regions, but life is far from being absent in and about the polar seas.

In the city there is life on every hand. Multitudes of human beings push us and crowd us on the street. In houses, warehouses, and stores we sometimes must combat such pests as rats, mice, flies, cockroaches, bedbugs, clothes moths, ants, and the invisible foes that we call germs. Certainly living things are abundant and of many kinds. These living things are a part of the environment wherever they may be found.

Organisms. All living things, whether they are plants or animals, are called organisms. We have seen that a separate kind of organism is called a species. There are now about 1,100,000 species of organisms which have been described and named. Of these, about 300,000 are species of plants and some 800,000 are species of animals. Probably many species, especially in tropical countries, remain to be described and classified.

SPECIES VARY IN SIZE

We have noted that there are many different species both of plants and of animals. Perhaps we know from experience that different species grow to different sizes. We may not as yet have realized that the individuals of the same species may vary in size, one from another.

Small plants. We have learned from observation that ferns and grasses in our temperate zone are small when compared with such plants as many elm or oak trees. In studying some of the algæ we find that there are plants much smaller in size than grasses, ferns, or mosses. Take, for example, Pleurococcus, which is a tiny green alga that often forms a greenish film upon the moist, shaded sides of tree trunks or rocks. Such a film

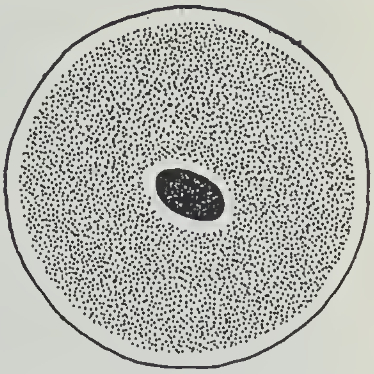

FIGURE 7. An alga (Pleurococcus) — highly magnified. One of the smaller and more simple plants.

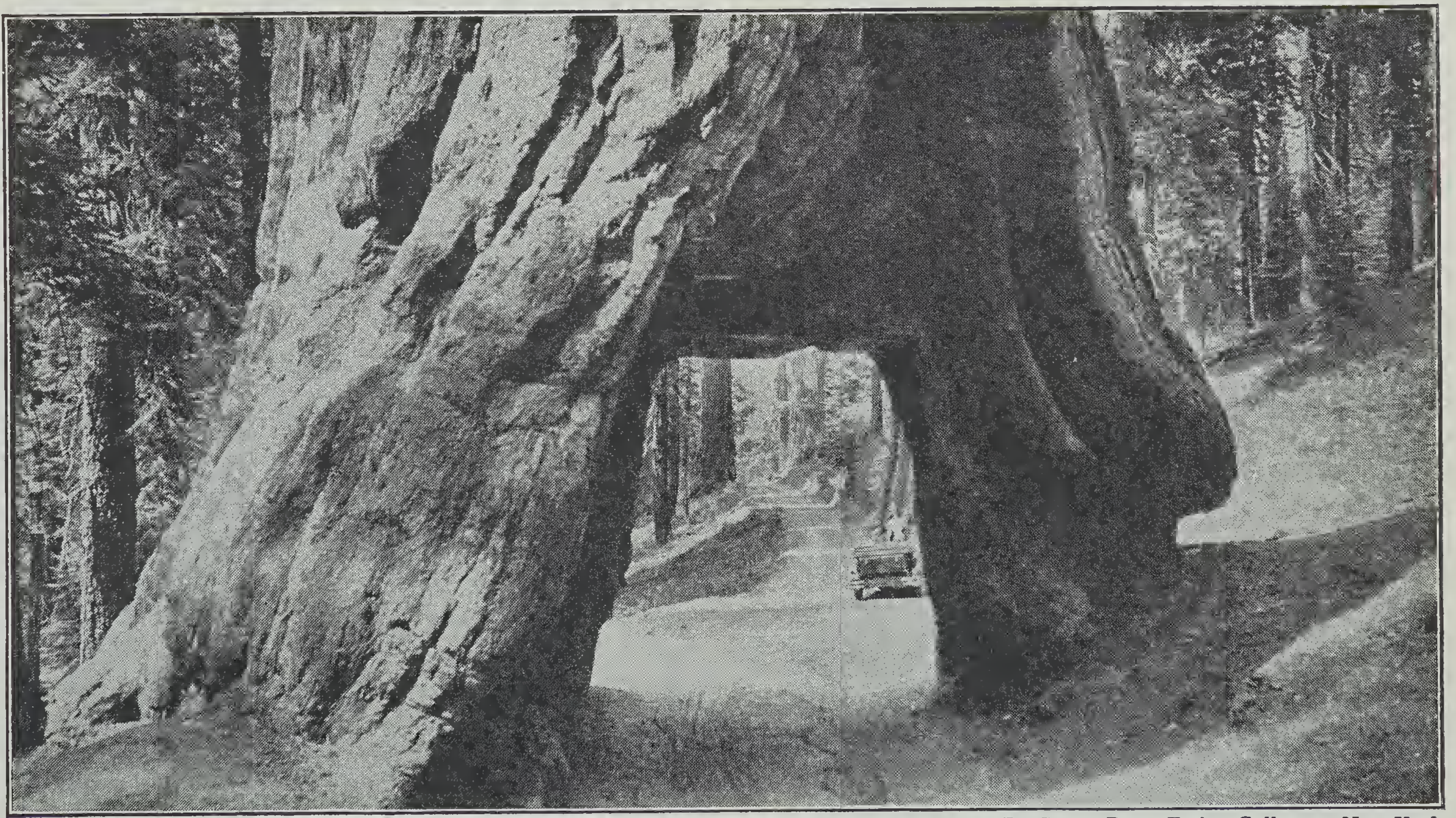

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FIGURE 8. A roadway cut through the base of a "big tree" in Yosemite National Park, California. Some of the sequoia trees in near-by regions are among the oldest living things.

represents the presence of many individual cells, which must be seen with the aid of a microscope. Many other algæ are very small, as are the numerous kinds of bacteria.

Large plants. On the other hand, the elm and oak trees are not the largest living plants by any means. The sequoias (trees) of California measure as much as three hundred and thirty feet in height and about thirty feet in diameter at the base. Some seaweeds are said to be over six hundred feet in length. We find, then, that different species of plants vary from massive structures to those which are microscopic in size. Do we find a similar variation in size among animal species?

Small animals. In studying the life of a pond, we have mentioned a number of familiar animals such as frogs and fishes. We have seen that in the water many much smaller animals are to be found. Some of these are visible to us only when magnified by the microscope's lenses.

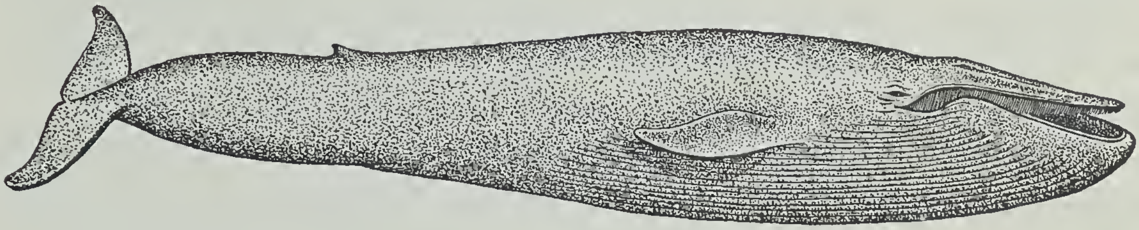

FIGURE 9. A sulphur-bottom whale. Is this the largest species of animal in existence? Were any dinosaurs larger?

Large animals. The largest living animals are the African elephant on land and the sulphur-bottom whale in the sea. The sulphur-bottom whale is estimated to weigh over one hundred and twenty tons, and to attain a length of ninety-five feet. The African elephant is much smaller, large specimens weighing about five tons.

We often read stories of great reptiles and mastodons of prehistoric times. It is interesting to note that no extinct animal of which we have any evidence weighed as much as the sulphur-bottom whale. We estimate the probable weight of extinct dinosaurs upon the basis of their fossil skeletons. But the largest of these, according to reasonable estimates, could have weighed no more than fifty tons.

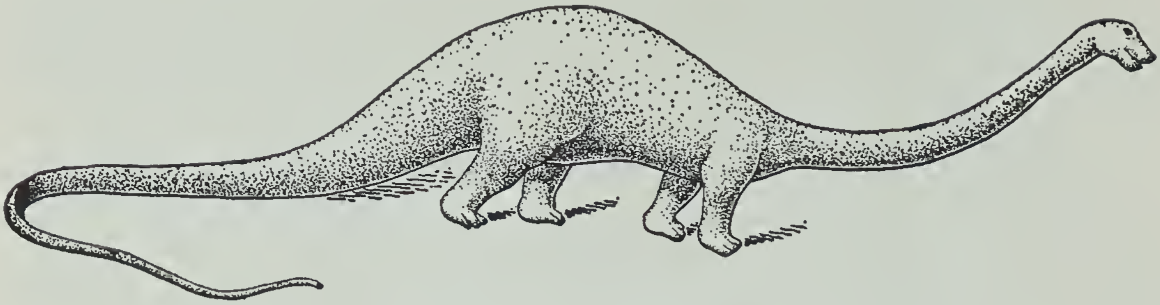

FIGURE 10. A dinosaur.

Problems of size. The discussion of size alone might fill an entire book and still leave many questions unanswered. Among such questions we find these: Why does each type grow to approximately one size and then stop growing? Is large size an advantage, or are small species more likely to be successful? Why are some children taller than either of their parents? Why are there such noticeable differences in size among individuals of the same species?

Summary. In conclusion, we find that each individual has an environment that includes all of its surroundings. Physical conditions, as well as other plants and animals, are factors in environment. There are many kinds, or species, of plants and animals in any typical environment. Finally, we have noted that these many species differ from one another as to size; in fact, that members of the same species may so differ. These are some of the first steps in gaining an understanding of environment, and the living things that are a part of environment.

SUGGESTED ACTIVITIES

Scientific methods

At the beginning of each list of Suggested Activities in the chapters which follow, there will be found a statement regarding some quality or method of a scientist. If we wish to improve our scientific abilities, we should give some thought to each of these statements. It is suggested, then, that each statement be discussed in the light of what has been learned in the accompanying chapter. The first statement is as follows: *A scientist learns facts by direct observation.*

1. Make an excursion to one or more of the following localities: (*a*) a fresh-water pond, (*b*) a forest area, (*c*) the seashore. Prepare a report upon the plant and animal life observed, with particular reference to variety of species, and important factors in the environment of any one species.
2. Obtain a culture of pond water which may be examined with the aid of the compound microscope or a micro-projector. Report upon the variety of species observed in such a culture. The culture may be obtained by dipping up some of the water and decaying organic materials at the margin of a stagnant, fresh-water pool.
3. Self-testing exercise. Which of the following responses is most appropriate for each statement?
    a. All of the things and conditions which surround a plant or an animal make up the (1) habit, (2) behavior, (3) environment, (4) natural enemies.
    b. All living things are (1) trees, (2) organisms, (3) green plants, (4) parasites.
    c. The largest living animal is the (1) African elephant, (2) sulphur-bottom whale, (3) kangaroo, (4) leech.
    d. The smallest type of plant in the following list is a (1) Pleurococcus, (2) sequoia tree, (3) elm tree, (4) fern.

SUMMARY OF PRINCIPLES

1. The surroundings of an organism make up its environment.
2. An environment is complex, consisting of many factors. It includes other organisms and physical conditions.
3. There are some 1,100,000 species of organisms now known and classified, of which the majority are animals.
4. Species differ as to size from those only visible with the aid of a microscope to those whose weight is measured in tons.

GUIDE QUESTIONS

1. What is meant by environment?
2. Give an example to show how physical surroundings may affect the life of a plant or an animal.
3. Name five factors present in the environment of human beings living in the city, but not present in the environment of those living in the country.
4. What is meant by "organism" and "species"?
5. About how many species have been named and classified?
6. What is the largest living type of animal? of plant?

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Chapter II

ENVIRONMENT AND ADAPTATION

Problems:

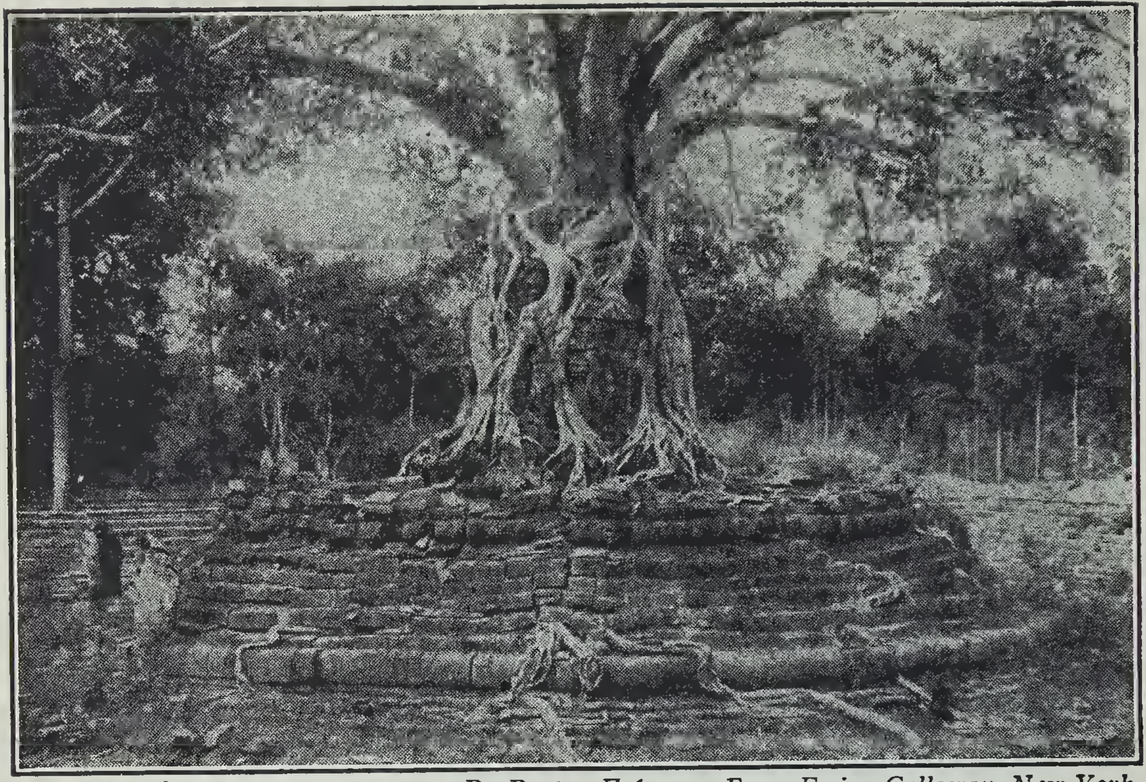
1. What do we mean when we speak of the "habitat" of a plant or animal?
2. Are individual plants and animals always found in the most favorable situations for successful life?
3. What are "adaptations"?
4. Are adaptations in any way related to habitat?
5. Is the welfare of animals related to the welfare of plants?
6. Is any organism independent of other organisms which live in the same habitat?

HABITAT IS THE PLACE WHERE A PLANT OR AN ANIMAL LIVES

In the preceding discussion we have learned that the environment includes many different kinds of living things, which are diverse in size. These living things or organisms are found living in many different situations.

Habitat. Generally speaking, it appears that every plant and animal has some sort of home. While a frog usually lives in and about the water, grasshoppers are found in fields and pastures. An earthworm burrows in the soil, but the codfish lives in the sea. Among plants, we find mosses growing in damp, shady places while daisies thrive in dry fields and in bright sunlight. Each kind of organism seems to live best under a certain set of conditions. The environment in which a plant or animal usually occurs is called its habitat.

Individuals are sometimes found in rather unusual places — living under conditions to which they are not well suited. When a plant, for example, is found growing in a certain place, it shows that it can grow there, but it may be better fitted for growth elsewhere. If coconut palms are found growing on certain



By Burton Holmes. From Ewing Galloway, New York.

FIGURE 11. An example of unusual root development (Indo-China).

islands it may be that water and winds have carried coconuts there. These coconuts sprouted and took root. They were able to get enough food material from the soil and air, and enough energy from sunlight to continue their growth. They might grow much better, however, in a warmer climate, or on a different soil.

Change of habitat. Many plants and some animals are unable to move about from place to place. They must live their lives where the individual happens to have been produced. Thus if a seed falls upon rocky soil, and sprouts, the new plant is unable to change its location. Some adjustments may occur, however, that will enable the plant to survive under the comparatively unfavorable conditions. It may develop long roots that pass around or between rocks and reach moist soil, while at the same time they provide a secure anchorage. A plant growing under these conditions would not be situated in an entirely favorable environment.

Conditions such as the foregoing do not occur in the case of

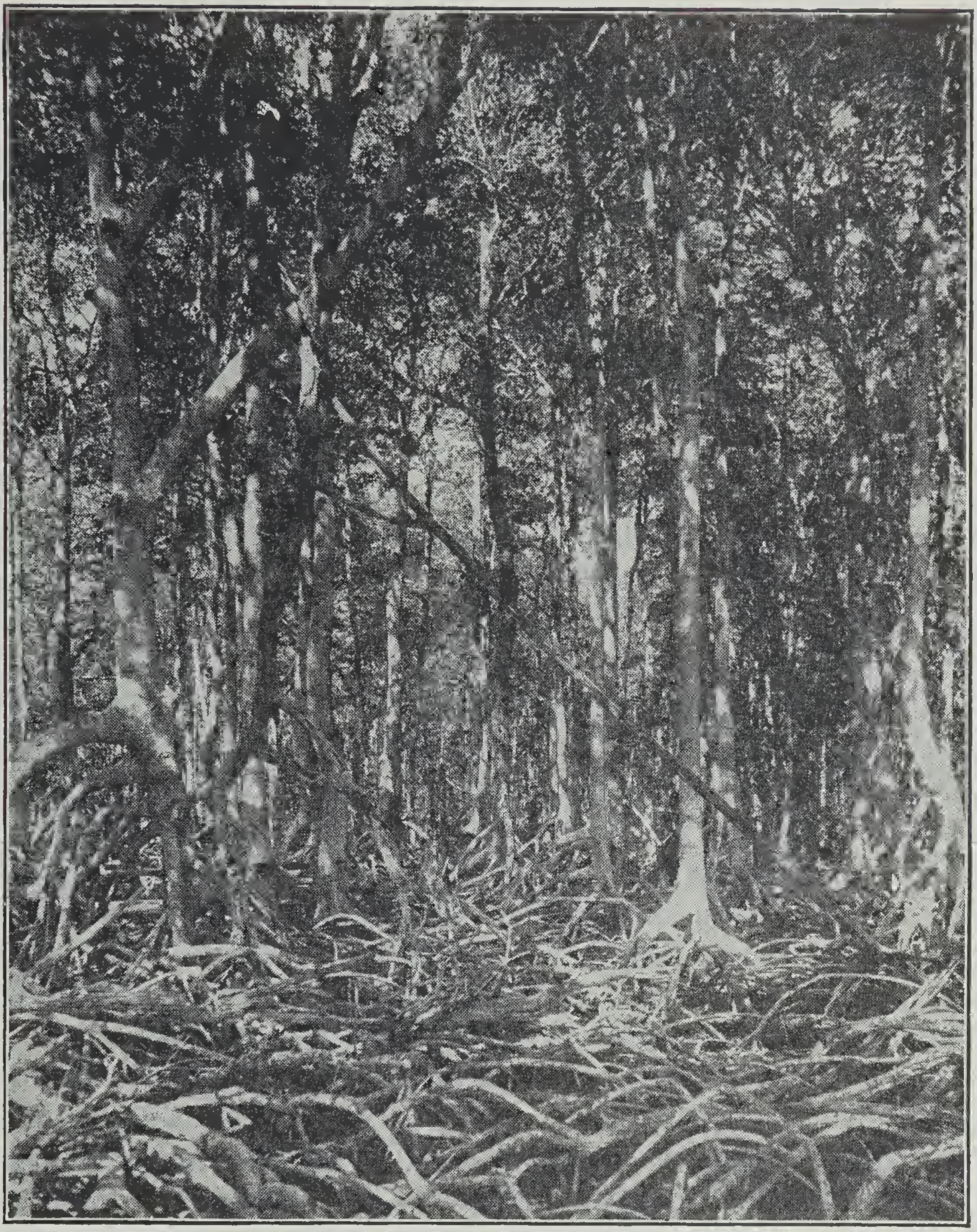


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FIGURE 12. A Florida mangrove swamp scene.

all organisms. If an organism is able to move from place to place, it is likely to desert unfavorable surroundings and seek a more suitable habitat. If man were the organism in question, he might not move, but might attempt to improve the environment.

ORGANISMS MAY SHOW ADAPTATIONS TO THEIR ENVIRONMENTS

Habitat and structure. Many species are more or less satisfactorily adjusted to the conditions under which they live. We found the leopard frog living in or about the fresh-water pond. We now may inquire to what extent this animal is suited to life under such conditions.

To this question a number of answers might be given, only a few of which will be considered here. For one thing, a frog's eggs must be deposited in the water, because they will not develop into tadpoles if placed upon the land. Also, the tadpole stage of a frog's development must take place in the water. This is because the young tadpole does not have lungs with which to breathe air directly. The tadpole, however, has gills, and is able to obtain oxygen from the water.

An adult frog develops lungs, and is an air breather. It also obtains some oxygen through its moist skin. This fact is of importance, because an adult frog does not abandon the water entirely. When winter approaches, a frog returns to the pond, and buries itself in the mud at the bottom. It lies there throughout the cold season, in a state of dormancy. During this period of time it depends upon stored food materials for its supply of energy. It obtains oxygen from the water, through blood vessels in its skin. Here we find another circumstance which tends to make the pond a favorable habitat for a frog.

As to the food habits of the leopard frog, we have noted that the adult feeds upon various species of insects and worms which are common about fresh-water ponds. The student might guess that the food habits of a tadpole must be somewhat different, because the tadpole is confined to the water. Such proves to be the case. The tadpole feeds upon a variety of small organisms that live in the water, many of which are not ordinarily eaten by an adult frog. But although the food habits of tadpole and adult differ, the food habits of both are associated with a fresh-water habitat.

A fish. Now let us consider the case of a fish — a carp, for instance. On land such a fish is a floundering, wriggling object.

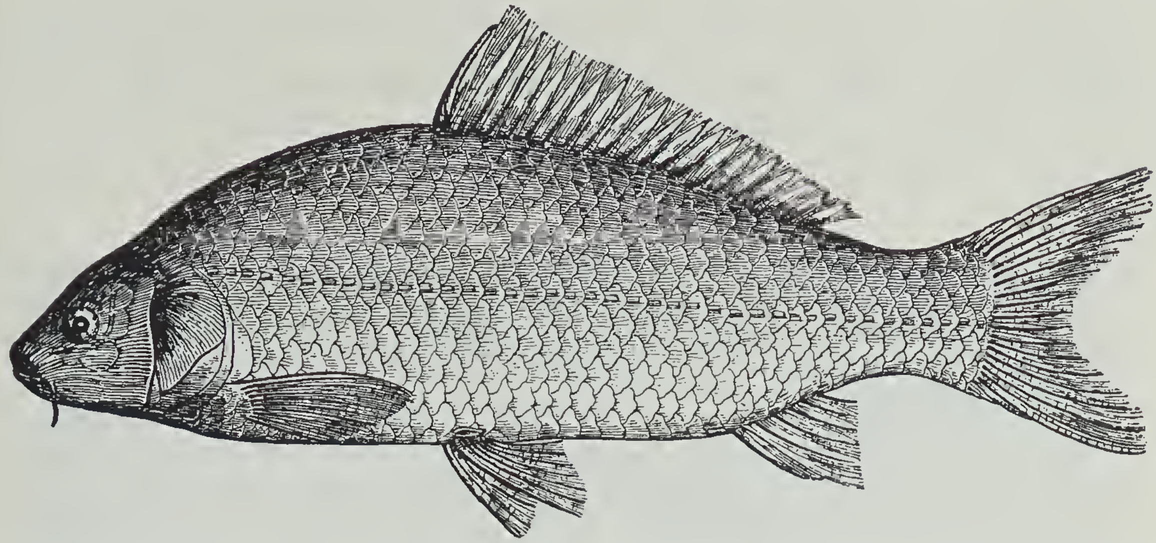

FIGURE 13. A carp. What adaptations related to life in a water habitat do you observe on this animal?

It is a gill-breather and when transferred to the land it cannot breathe effectively. On land it cannot walk or crawl or jump after the manner of land animals. If it is not returned to the water, it will soon die.

On the other hand, when in the water, the carp is able to obtain oxygen and food. Its tail and fins propel the body from place to place at a good rate of speed. Hence we are able to see that while the carp is "at home" in the pond, it is unable to survive on the land. The carp is what we call an aquatic animal; one that has its habitat in the water.

An earthworm. An earthworm is suited to life in the soil. It is able to survive for a time when in the water, but it is not prepared to live an aquatic life. If it is forced to remain upon the surface of the soil, exposed to the rays of a hot summer sun, it soon dries up and dies. An earthworm has neither lungs nor gills, but obtains oxygen through the surface of its body, which must remain moist if this process is to continue. Probably any extensive drying would stop this activity. In moist soil, however, an earthworm burrows about, feeding upon decaying plant and animal materials that are a part of this soil. It is able to find food and to carry on other life functions successfully. It is a subterranean animal; one that ordinarily lives in the ground.

A dog. A dog is able to carry on its life activities on land. While it can swim, it is not able to breathe under water. Nor does it live underground or in trees. It is a terrestrial animal; adapted to life on the surface of the ground.

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FIGURE 14. Birds in flight (wild geese).

A bird. A bird, such as a swallow, is able to fly through the air. This power of flight depends, of course, upon the possession of wings. But the wings could not function without the presence of certain muscles. The muscles could not perform their work unless efficient breathing, digestive, and other structures were present to supply food materials and to remove waste products. A swallow may be called an aerial animal because it possesses the power of flight.

Adaptations in general. A tree sways in the wind and its branches swing up and down and to or fro. Yielding to the wind may prevent breaking. A duck's webbed feet are admirably suited for paddling through water. Its flat, spoon-like bill is effective for scooping up food out of the mud and water. The coloration of a grasshopper causes it to resemble the dried grasses upon which it may be resting. Perhaps this tends to conceal a grasshopper from possible enemies. The gills of a tadpole and a carp enable them to obtain oxygen from water. The lungs of an adult frog and of a dog enable them to breathe air directly. An earthworm is suited for life in a moist soil containing such food as decaying plant and animal matter. The wings of a swallow are used in flying, and the webbed feet of a duck are used in swimming. The branches of a tree yield to the force of the wind. These and many other features of structure may be regarded as adaptations. They are features of structure (involving habit) which make life possible under certain conditions. To a large extent, habitat is determined by the structures which the organism possesses.

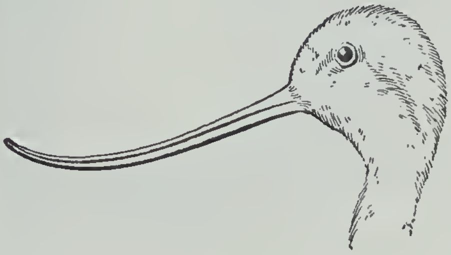

FIGURE 15. A bird bill used for feeding along the shores. What adaptations of legs and feet might such a bird have?

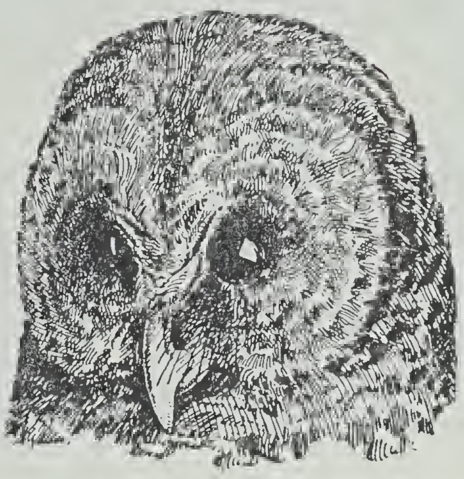

FIGURE 16. The beak of an owl — a structure which is used effectively in tearing the flesh of the owl's prey.

Adaptation of behavior. The word adaptation also is used in referring to changes in behavior. Suppose, for instance, that certain tiny, single-celled animals are living in a pond. The pond gradually becomes dry in midsummer. Some of these organisms develop protective coverings (cysts) in which they remain inactive, but alive. When rains come and the pond is filled with water, the cysts may be dissolved, and the animals within them may resume active life. In this example we find that behavior has been adapted to changing conditions of life.

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FIGURE 17. A group of penguins. These birds are excellent swimmers and divers, but are unable to fly.

THERE ARE MANY INTERRELATIONSHIPS AMONG ORGANISMS

Let us now consider some adaptations of structure and habit possessed by some of the plants and animals that live in or about the fresh-water pond. We wish to see in what ways the life and habits of one organism may affect the lives of other organisms.

Green plants and the food supply. It will be recalled that many species of algæ are to be found among the plants living in the water. These algæ consist of simple plant cells, some living separately, others living in colonies. When we examine the structure of such cells, we find that they contain the green material known as chlorophyll. This is why some algæ are green in color; in others the green of the chlorophyll is masked by different colors.

Plant cells which contain chlorophyll are able to manufacture sugars from the inorganic materials, carbon dioxide and water. The energy for this process comes from sunlight. So the algæ are able to make sugar, which is a basic food, from water and carbon dioxide which are available all around them.

It is important to note that, with the exception of one group of bacteria, no organism which does not contain chlorophyll is able to carry on the process of food manufacture. Animals cannot manufacture foods from inorganic compounds, but must obtain them directly or indirectly from green plants. Hence these algæ form one basic source of food supply for other organisms that live in the water.

Bacteria. Some cattails, rushes, grasses, and other green plants are found around the borders of our pond. From time to time portions of these plants break off and fall into the water. Here they decay, this process being hastened by the fact that many of the tiny bacteria use them as food material. The same or other bacteria may obtain food materials from dead algæ or any dead animals that may be in the water. Much of the decay of dead organisms is caused by the action of certain bacteria upon them. Some bacteria may live at the expense of living animals or plants.

Protozoa. We have mentioned the fact that many simple animals called protozoa are found in the water. Most of these

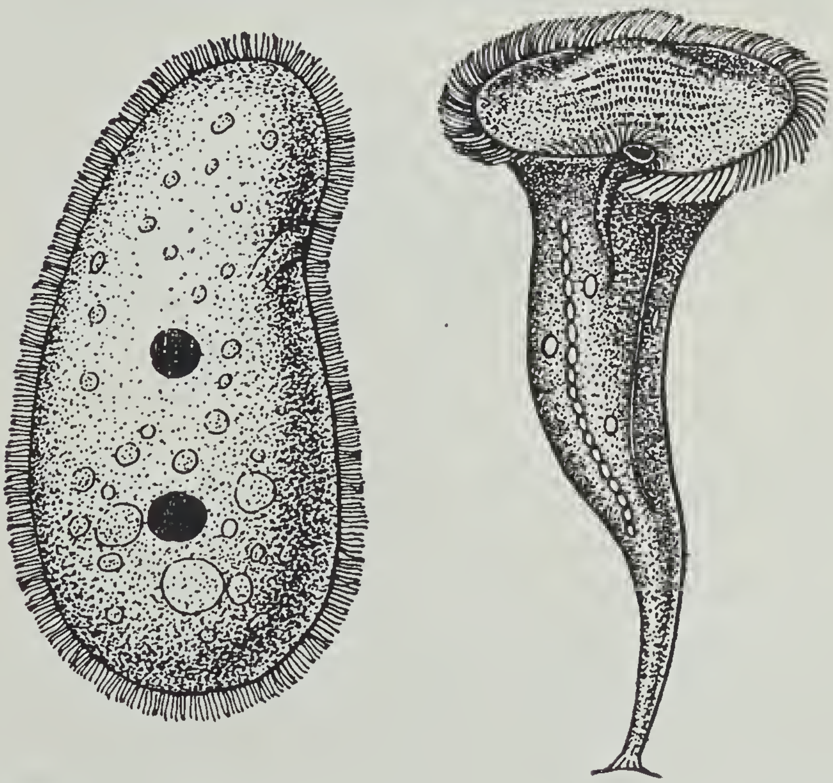

FIGURE 18. Diagrams of two protozoans, greatly enlarged.

animals are microscopic in size. They are, of course, unable to manufacture food materials. They feed upon algæ, bits of larger plants that have been broken up by decay, other protozoans, and in many cases bacteria. Some of these small animals practice a form of cannibalism; that is, they "eat" smaller members of their own species. An example of this practice occurs in the case of Amœba.

Already we see that the lives of these tiny organisms living in the water are interrelated in a very marked way. Every species is a factor in the life or the environment of the other species. The presence of chlorophyll in green plants might be called an adaptation that is necessary to the process of food-making. As such, it becomes very important in the lives of all animals.

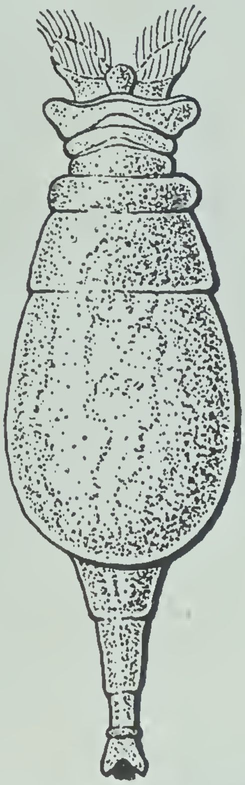

FIGURE 19. Diagram of a rotifer, greatly enlarged. Is this organism a protozoan or a metazoan?

Rotifers. The chain of interrelationships does not end with the smaller animals, however. For many of these species, together with both large and small plants, serve as a source of food supply for larger animals. One group of tiny animals, which depend upon protozoans and other smaller organisms for their food supply, includes the rotifers. These rotifers are not protozoans, because their bodies are composed of many cells. Nevertheless, when we compare them with our familiar land animals they are small in size. We must depend upon the microscope in studying their structures and behavior.

Aquatic insects. The shallow water along the shore may be teeming with insect life, and many of these insects feed largely or entirely upon other small animals. In some cases, these insects pass their entire lives in or about the water. In other instances, as in the familiar case of the mosquitoes, only the first stages of the life cycle are confined to the water. Winged adult mosquitoes live in the air or on the land. Tadpoles, and many of the smaller fishes, depend upon the small organisms in the water for their food supply. Thus we find that a mosquito larva, which feeds upon tiny animals, is in turn eaten by minnows and other natural enemies. Small fishes or minnows may then be captured and eaten by the young of dragon flies, which also live in the water, or by giant water bugs. We then have the spectacle of a small fish which eats insect larvæ (mosquitoes) and is in turn eaten by insects.

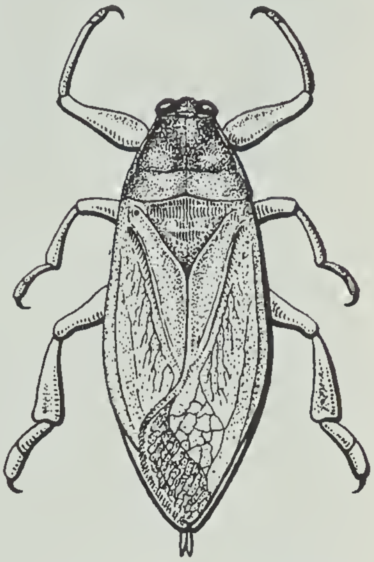

FIGURE 20. A giant water bug.

Crayfish. Our pond may contain crayfish, which feed upon decaying plant materials, tadpoles, insects, and snails. These crayfish are members of the crustacean group, and they are not the only members of this class of animals that we may find in ponds. On the contrary, there will probably be a number of smaller crustaceans, some of them so small as to be microscopic in size. All of these different crustaceans may serve as food for the larger animals found in the water, and more particularly as food for the fish.

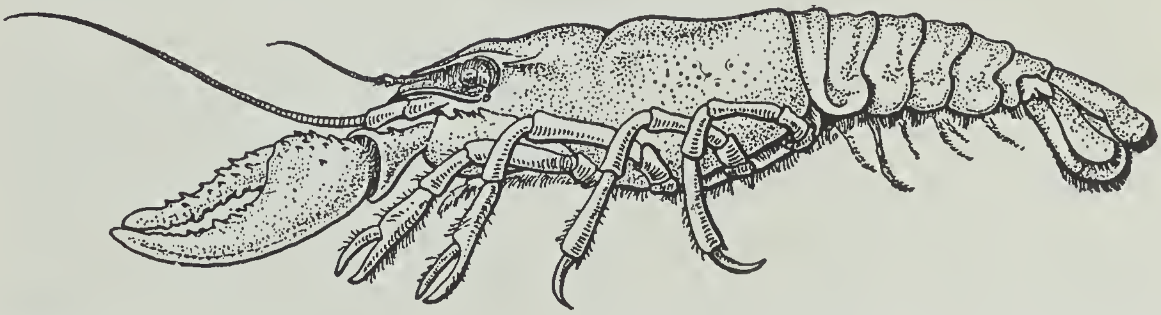

FIGURE 21. A crayfish. Are the structures of this animal more like those of a carp or those of a grasshopper? (See Figures 13 and 82.)

Snails and clams. If we explore the bottom in the neighborhood of the shore we may find some fresh-water snails and fresh-water clams. The clams found here will be small — their larger relatives probably are present but are in deeper water. The clams obtain food in the form of microscopic organic material

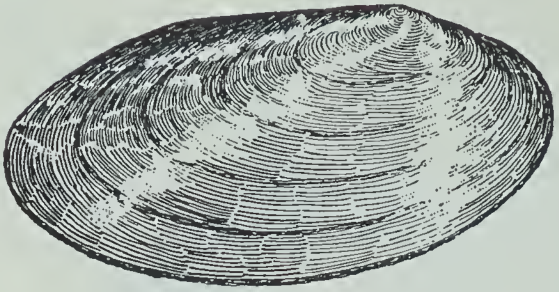

FIGURE 22. A clam

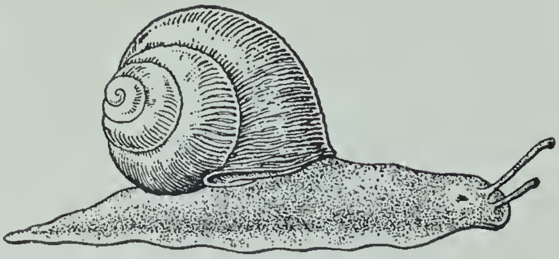

FIGURE 23. A snail.

that is in the water. Snails feed largely upon plant materials. Both clams and snails may in turn be eaten by a variety of natural enemies, such as fish. Muskrats sometimes obtain the smaller species of clams, break them open, and eat the fleshy parts.

Fishes. Several species of fish are probably present. These may range in size from minnows and young fish which have been hatched during the course of the summer, to bullheads that weigh two pounds, and carp that weigh as much as ten pounds. To some extent these fish prey upon smaller animals; this habit varies, depending upon the species of fish in question. They may feed upon microscopic plants and upon the larger plants that grow in or about the water. A carp, for example, may eat the roots of plants that grow along the shore.

The various species of fish have natural enemies of their own. Water snakes include fish as well as frogs in their diet. So do some species of turtles — the snapping turtle and the soft-shelled turtle, for example. Kingfishers, herons, some ducks, and other species of birds are likely to visit the pond and prey upon the smaller fish. Minks and raccoons are fond of fish, and may make nightly visits to the shore.

Parasites. We have already referred to the fact that fresh-water ponds contain numerous species of organisms, such as

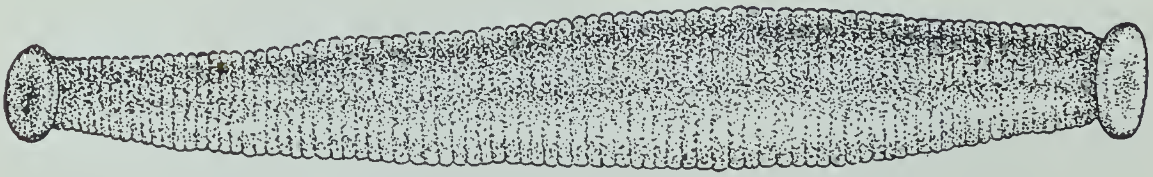

FIGURE 24. A leech. What adaptation for obtaining food can be observed?

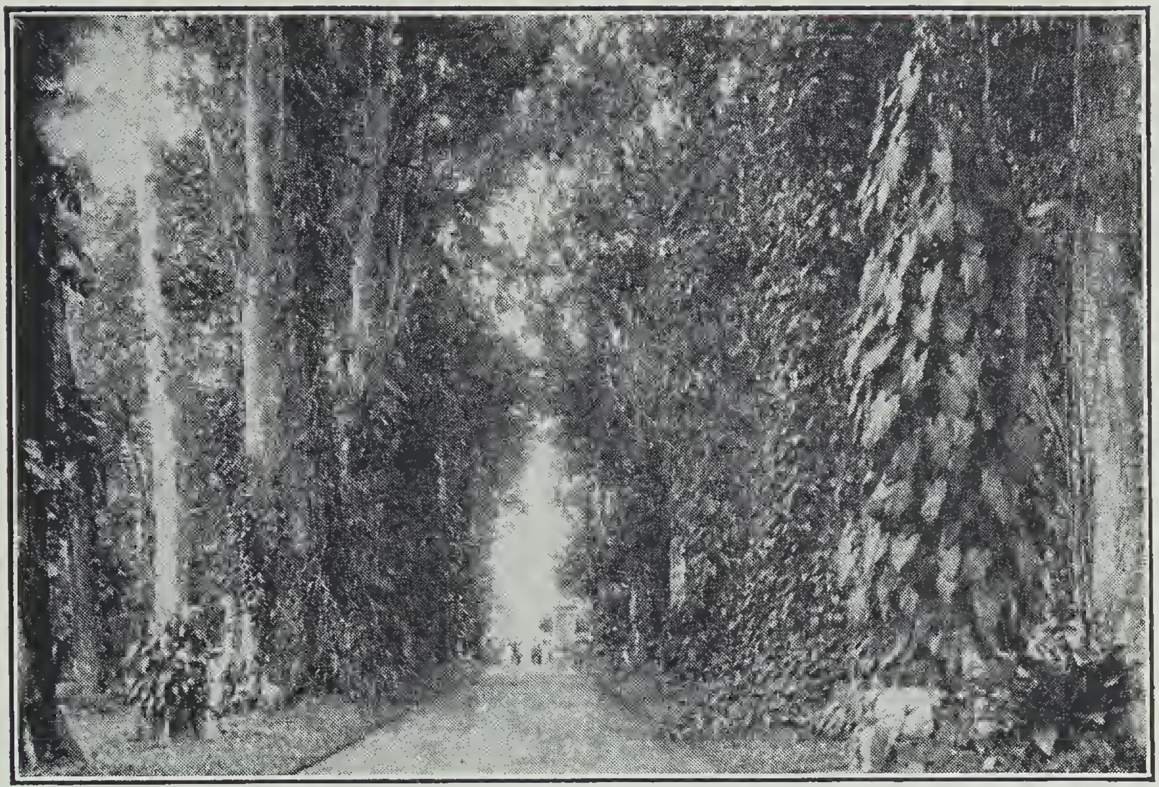

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FIGURE 25. Trees with vines growing upon them (Batavia).

certain bacteria, leeches, and roundworms, which live in or upon the bodies of other organisms. They obtain nourishment from the latter without giving any benefits in return. Such bacteria, roundworms, and leeches are known as parasites. The animals that support them are called the hosts. These parasites are an important feature of fresh-water life, since their presence may result in the death of many of their hosts.

Relationships. We are now able to see that life in a fresh-water pond involves many complex relationships. One species preys upon another species and is in turn preyed upon by a third species. The animals either eat plant materials, or prey upon other animals, or eat both plant and animal materials. All of the animals owe their existence to food materials that originally were manufactured by plants.

The environment of any organism living in a pond involves many different factors, only a few of which have been suggested here. The life of any species may be affected greatly by the presence or absence of some other species.

Interrelationships of species are not illustrated by fresh-water organisms alone. Much the same sort of story is revealed to us when we study the interrelationships of species living on the land or in the sea. The basic principles remain the same in either case, although the species living in the various habitats are different.

Some interrelationships are more likely to attract attention than are others. We are familiar with the facts that ferns and mosses frequently grow in places where the soil is moist. Often such places are moist because they are shaded by trees. Grapevines may grow upon trees, using the support of the latter in reaching the sunlight. Some insects obtain their food by sucking the juices of plants. Some plants live upon other plants or animals and draw their nourishment from them.

Summary. It appears, then, that each species is best adapted to a certain environment which is known as its habitat. The particular kind of habitat seems to depend upon the structures or adaptations of the species in question. This is another way of saying that organisms may have special adaptations which make it possible for them to live in certain habitats. This does not mean that a structure is developed to enable the organism to live in a certain place. Rather, the organism lives in a certain place because it happens to possess certain structures. Some changes in habit or behavior are also known as adaptations. The lives of plants and animals living in a community are not independent. Green plants furnish the basic supply of food. The lives of all organisms living in a community are interrelated.

SUGGESTED ACTIVITIES

Scientific methods

A scientist outlines his purposes and his plans before beginning an investigation.

1. From observations made on a field trip, report upon special or outstanding cases of adaptations.
2. Make a field trip to a fresh-water pond. Obtain a culture of the water (see page 9). Observe, and in so far as possible identify

species of plants and animals in or about the water. Examine the culture of pond water to see what smaller organisms may be present. Learn the food habits (see page 28) of the types recognized, and indicate cases in which the lives of various types are interrelated because of their food habits.

3. If unable to make a trip into the field, prepare a similar study of the food habits of (*a*) Paramecium, (*b*) a green alga living in the water, (*c*) a rotifer, (*d*) a crayfish, and (*e*) a bony fish.
4. With the aid of the instructor, examine the contents of the food canal of a fish.
5. If a fish were a terrestrial animal, what adaptations, or changes in structure, would you suggest as being necessary for this kind of life?
6. Prepare exhibits of habitats or interrelationships of various organisms; these may be models of drawings.

SUMMARY OF PRINCIPLES

1. Habitat refers to the special type of environment in which the organism usually is found.
2. The individual is not always found in the most favorable situation for its growth and development.
3. Organisms may possess adaptations to their environments in the form of special *structures*. Habitat may be determined by structures which the organism happens to possess.
4. The organism may adapt its *behavior* to the conditions of the environment.
5. Animals are dependent, directly or indirectly, upon green plants for their food supply.
6. Some organisms live at the expense of other living organisms; these are called parasites.
7. There are many interrelationships among organisms.

GUIDE QUESTIONS

1. What is meant by "habitat"?
2. Describe the habitat of some animal. Of some plant.
3. What is the distinction between the terms "environment" and "habitat"?
4. What sort of organisms are most likely to be found in comparatively unfavorable environments?
5. Is there any relationship between the structure of a tadpole and its habitat?

6. Name an aquatic animal, a terrestrial animal, a terrestrial plant, and a subterranean animal.
7. Give an example of adaptation.
8. What raw materials are used by a green plant in manufacturing food? What is the source of energy for this process?
9. What are "bacteria"? "protozoa"?
10. What are "parasites"?

BOOKS TO READ

Comstock, J. H., Comstock, A. B., and Herrick, G. W. *A Manual for the Study of Insects.*
Curtis, C. C. *Guide to the Trees.*
Durand, H. *Field Book of Common Ferns.*
Morgan, A. H. *Field Book of Ponds and Streams.*
Peterson, R. T. *A Field Guide to the Birds.*
Ward, H. B., and Whipple, G. C. *Fresh Water Biology.*

Chapter III

THE CONDITIONS OF LIFE

Problem:

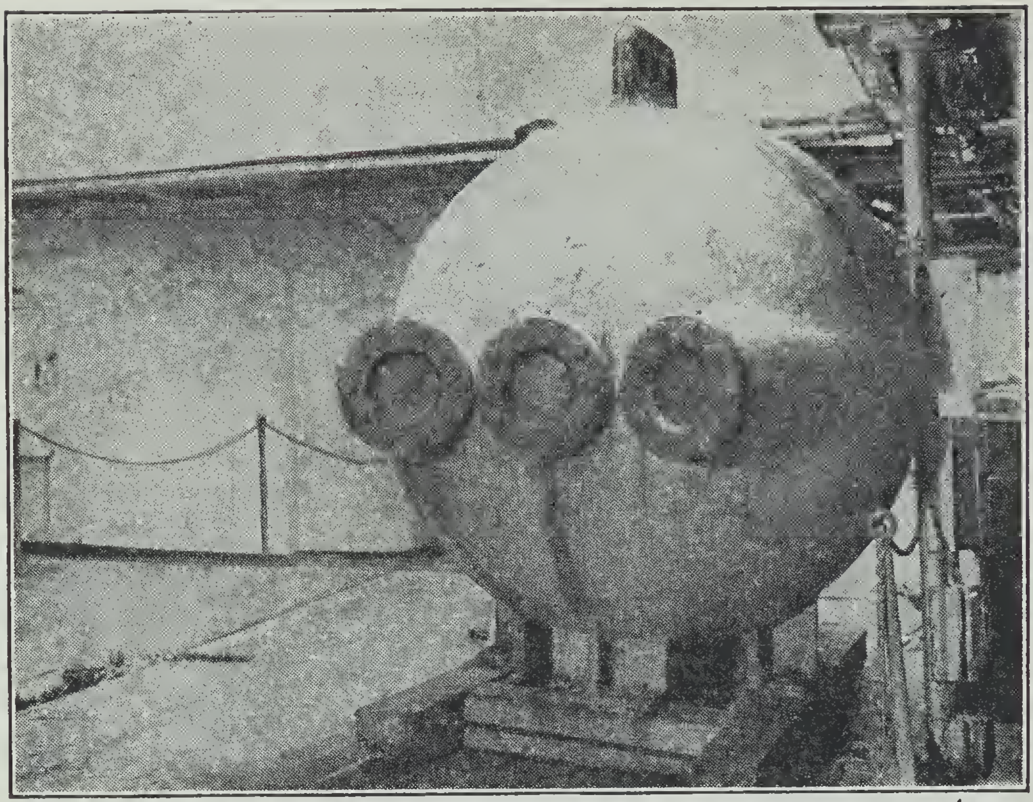
To what extent are living things affected by conditions of pressure, the presence or absence of water, oxygen, and food, and temperature?

MOST LIFE IS FOUND ON OR NEAR THE EARTH'S SURFACE

In studying the life of a fresh-water pond we have found that the organisms living in such a locality have certain structures or adaptations which make aquatic life possible. Likewise, animals and plants living on the land are more or less adapted to this type of habitat. The question now arises: Are there situations in nature where conditions are so unfavorable as to prevent the success of plants and animals? Are organisms able to live under all existing extremes of temperature, pressure, and other physical factors? Are there any conditions which limit life?

Exploring the deep sea. For some years the island of Nonsuch (Bermuda) has been the headquarters of a very interesting biological laboratory. The members of its staff have been studying marine life. They have collected and observed not only the more common organisms that live in shallow water, but also the less well-known animals of the depths.

Some of the collecting has been done by dragging a series of nets on two-mile-long cables behind a tugboat. Many hauls have been made in this manner. Although Dr. William Beebe and his assistants have attempted to keep the captured animals in a living condition by putting them in cold sea water, most of them soon died, because they were unable to adjust to the changes in pressure, temperature, or light. Nevertheless, it has been possible to learn many things about these animals that normally live well below the surface of the sea. We discover how different life may be in such a place.



Acme.

FIGURE 26. Dr. Beebe's bathysphere. What regions are explored through use of this device?

Conditions of life in the deep, a mile beneath the surface of the ocean, are very different from conditions in shallow water. Dr. Beebe has explored to great depths, not only by use of nets, but also by means of his specially constructed diving bell (bathysphere) with glass windows. He reports that darkness, icy cold, complete silence, and tremendous pressure constitute the conditions at depths of about one mile.

To live under such conditions, adaptations and interrelations which appear strange to us seem necessary. Many of the animals have light-producing organs. Some have enormous eyes. Other species with small eyes have marvelous long feelers, tentacles, or streamers, which keep them aware of their surroundings.

The period of exploration in various fields of biology is not over. Dr. Beebe is an explorer; Professor Morgan, working with his microscopes, is an explorer. Life is being explored on every side. Let us see what is known of the border lands of life.

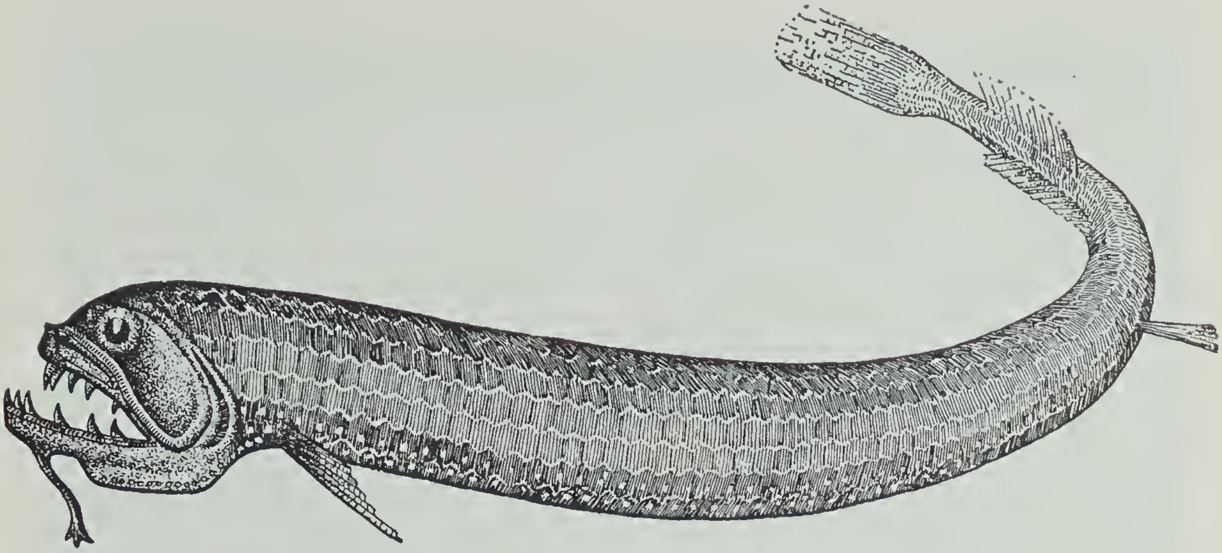


FIGURE 27. A deep-sea fish.

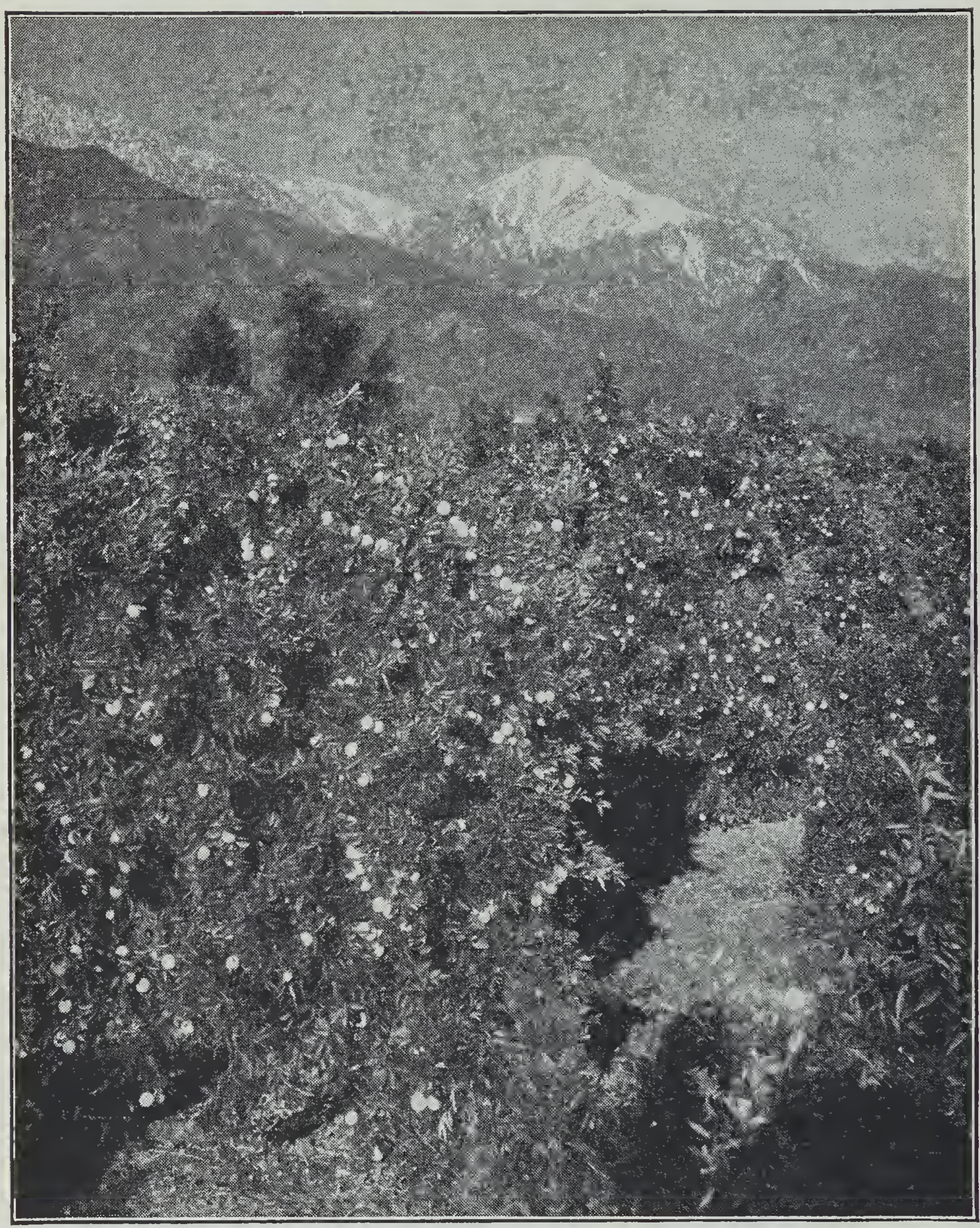
First we may inquire into the question of how altitude affects living things.

Does altitude affect life? As we ascend a mountain, for example, Long's Peak in Colorado, the vegetation becomes thinner and more scattered. Many of the animals found at lower altitudes become less common as we climb higher. Presently we come to a region known as "tree line" or "timber line," above which no trees are found. Beyond this "line" we encounter a few bushes, some mosses and lichens, and occasional tufts of grass, together with certain flowers.

Meanwhile it is probable that our breath has become "short." Our hearts beat faster. We find it desirable to go more slowly. We discover that someone in our party has a bleeding nose, and must discontinue the climb because of physical exhaustion.

If we continue our journey, we reach "snow line," above which, even in midsummer, snow may be seen. In such a place there is little indication of the presence of plant and animal life. The species known to us at lower altitudes are not represented here under normal conditions.

As we look toward other mountains we can see the forests of the mountain slopes change from a fairly dense growth in many places to the scattered, wind-torn, and stunted trees which are found at the tree line. Then above, there is a stretch of barren rock and soil, wet with water from occasional patches of melting snow, or at some seasons covered by white snow caps.



Ewing Galloway, New York.

FIGURE 28. An orange grove in a Southern California valley, with snow-clad mountains in the background.

High altitudes. The conditions of the upper layers of the earth's atmosphere are not well known. At altitudes of about four miles aviators without protection may become unconscious. The air here is thin, the atmospheric pressure is lower than at

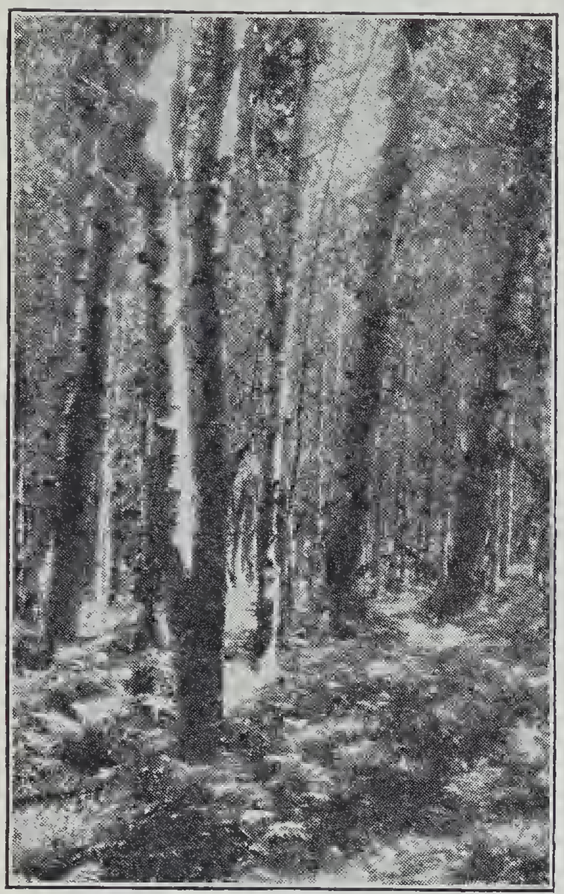
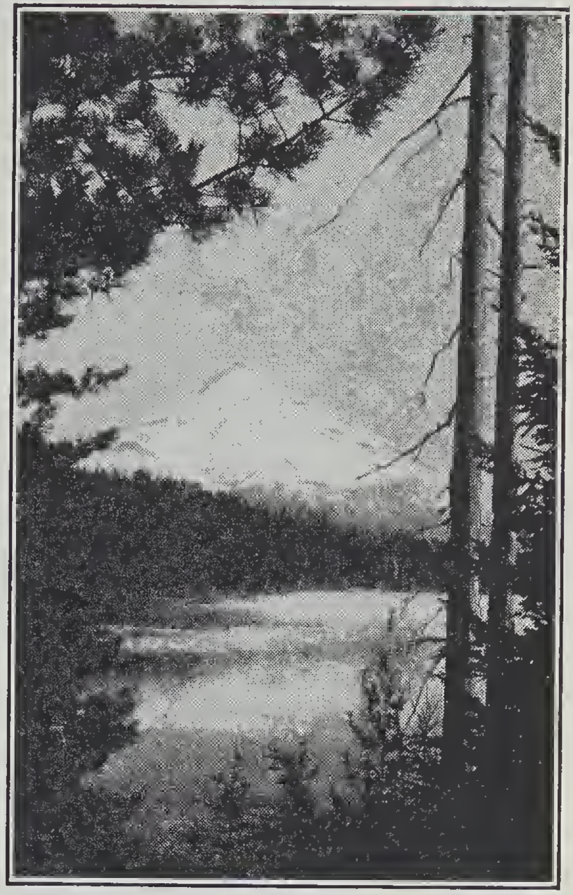


FIGURE 29. Aspen trees and ferns growing in a forest.



Courtesy of Mr. H. J. Miller.

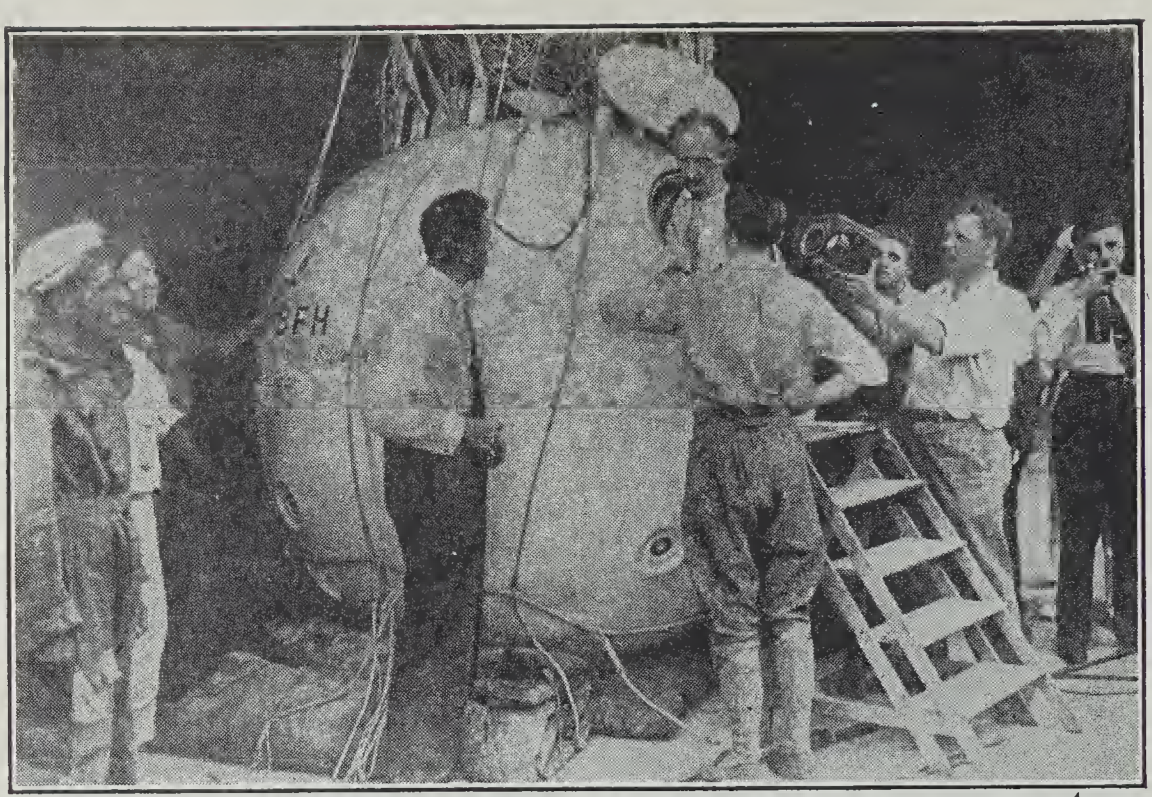
FIGURE 30. A snow-clad peak. Mount Hood.

sea level, and the cold is severe. A few years ago, Professor Jean Piccard ascended to a height of about ten miles. He accomplished this feat in a balloon having a specially designed living compartment in which he was supplied artificially with oxygen and heat, and in which normal atmospheric pressure was maintained. In the fall of 1933, Lieutenant-Commander T. G. W. Settle and Major C. L. Fordney[1] ascended to a height of over eleven miles, using a balloon of similar construction. In the fall of 1935, Captains A. W. Stephens and O. A. Anderson[2] ascended in a stratosphere balloon, Explorer II, to a height of over 70,000 feet.

Life in the soil. The roots of trees extend downward into the soil, often for a few feet only. Some earthworms dig burrows that go well below the frost line. They have been reported at depths of about twenty feet. Many other animals construct

[1] United States Navy and Marine Corps.

[2] United States Army.



Acme.

FIGURE 31. Professor Piccard, and the gondola of his balloon.

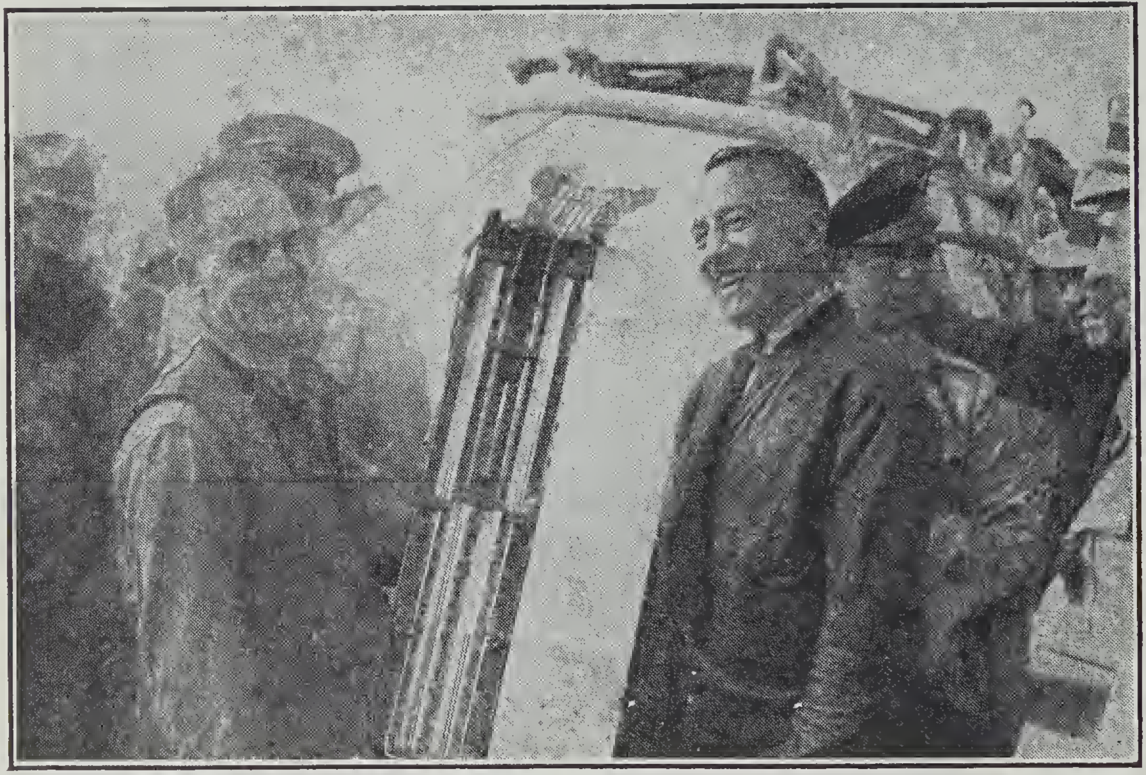


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FIGURE 32. Major Fordney and Lieutenant-Commander Settle.

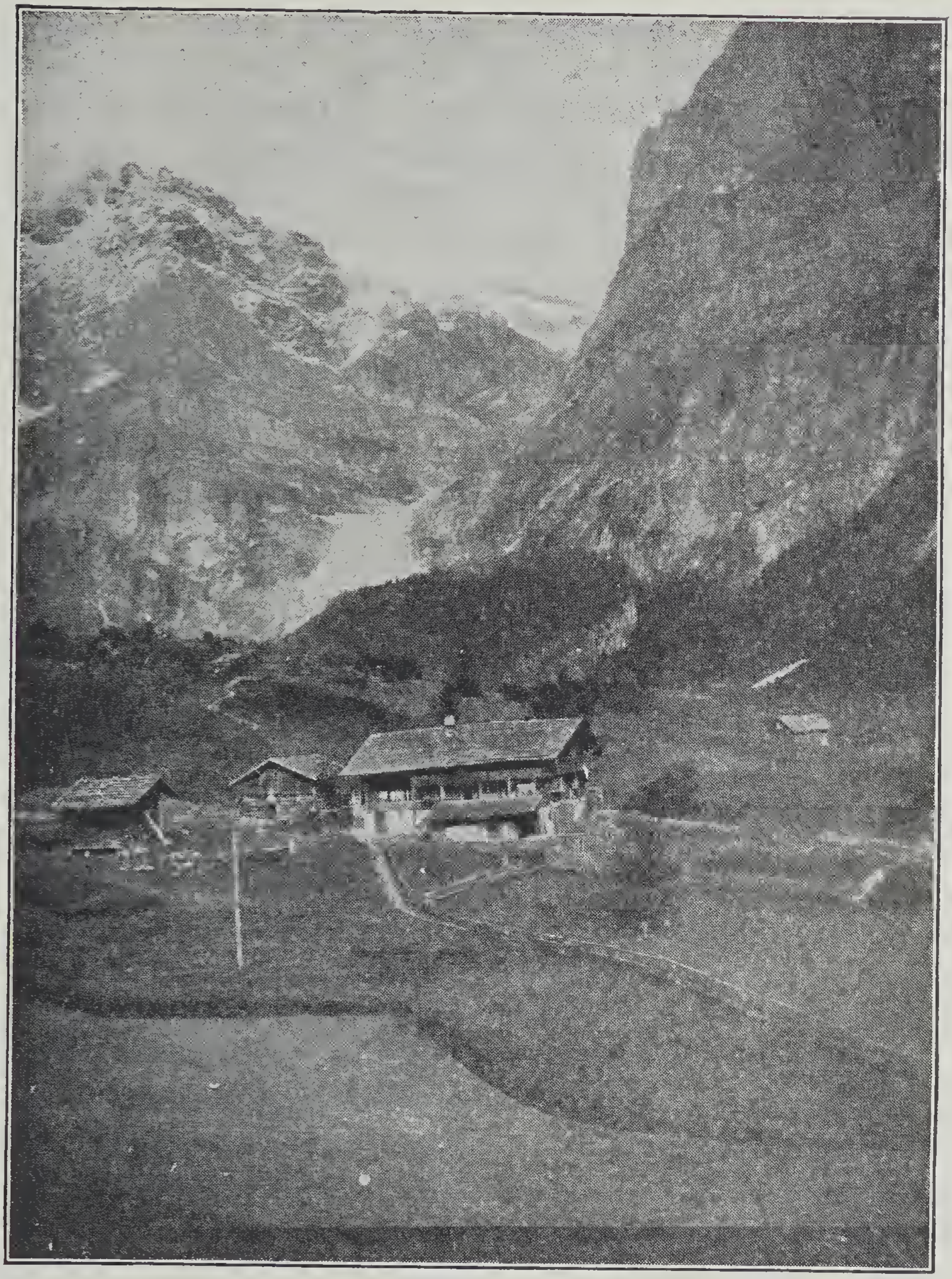

FIGURE 33. Mountain sides, showing the absence of trees at higher levels.

burrows, but most of them are rather shallow. Larvæ of insects are found as a rule only a few inches beneath the surface. Bacteria are present as deep as the soil is cultivated; some bacteria are found below this level.

As you travel along a newly cut roadway of a railroad or a public highway, observe the depth of the dark soil containing roots at the top of the cut. You will see that this is seldom more than a few feet. Below this is sand, or gravel, or clay, or rock, unmixed with either living or dead organisms.

Fresh-water fish. In bodies of water, life is found at somewhat greater depths. In fresh-water lakes fish may lie in water at least 200 feet deep. They usually come to the shallower places, however, or to the surface when seeking food. Most fresh-water fish live among or near the plants that grow along the shores.

PRESSURE AFFECTS LIFE

The familiar animals and plants of the ocean are the species that live on or near the surface and near the shore. The common food fishes and lobsters are found at moderate depths. Lobsters are found on the bottom at depths of 300 feet. This is, however, comparatively shallow water as compared with some of the ocean depths which are measured in thousands of feet. The Grand Banks of the northeastern coast of North America is one of the best regions in the world for commercial fishing. Here the water is not more than 1000 feet deep, and the average depth is about 240 feet. Even in this relatively shallow water, many fish are not found at the bottom, but occur in groups or "schools" near the surface.

Deep-sea life. In the sea we find that the number and variety of organisms decrease as the water becomes deeper. Here a very curious situation develops. It is possible for animals having special adaptations to live at great depths where the pressure is high, sunlight scanty or absent, and temperatures are low. A number of bony fishes have been brought to the surface from levels below 6000 feet. In a few cases it appears that fishes have been brought up by dredges from about 12,000 feet. Many of the lower animal types, such as starfishes, sea urchins, and related forms, have been taken at depths between 10,000 and 12,000 feet. Some species of animals have been brought up from the 23,000-foot zone.

The deepest ocean bottoms have not been explored completely.

Some of the fishes from the greater depths are among the most curious and grotesque forms of life to be found anywhere. It must be remembered that at depths exceeding 3000 feet there is little or no sunlight, the temperature is only slightly above the freezing point, and the pressure is very great. The depth to which sunlight penetrates the water is important because sunlight is necessary to the existence of green plants. Most green plants of the ocean are found in relatively shallow water, for there is little sunlight below the 600-foot level.[1]

The pressure of the water increases about fifteen pounds per square inch for every thirty-one feet of depth in salt water (approximately one half pound per foot). This would give a pressure in addition to that of the atmosphere of about 1500 pounds per square inch at 3100 feet.

The bodies of organisms that live in deep water are filled with liquids under the same pressure as the water in which they live. Hence the pressure within and without is the same upon all parts of their bodies. At the level at which they are accustomed to live, they are as well adapted to the pressure as are human beings who live in a "sea of air," where the atmospheric pressure is only fifteen pounds per square inch (at sea level).

It has been reported that fish caught at great depths and brought up to the surface "explode." To a certain extent this is true, since such fish often do swell when they are brought up rapidly from deep water. It even is possible that certain parts of their bodies may burst or be injured as a result of the sudden release from high pressure. On the other hand, some species of animals are found on several levels. Some species of fish are said to come to the surface from a depth of over 3000 feet.

Adaptations of whales. A few animals appear to have adaptations for living at various depths in the sea, and to make the change from one level to another quickly and without injury. Some whales, for example, dive deeply upon being harpooned, or when seeking certain animals upon which they feed. It has been estimated that one species (sperm whale) may go down

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[1] Ultra-violet rays of sunlight may penetrate to greater depths.

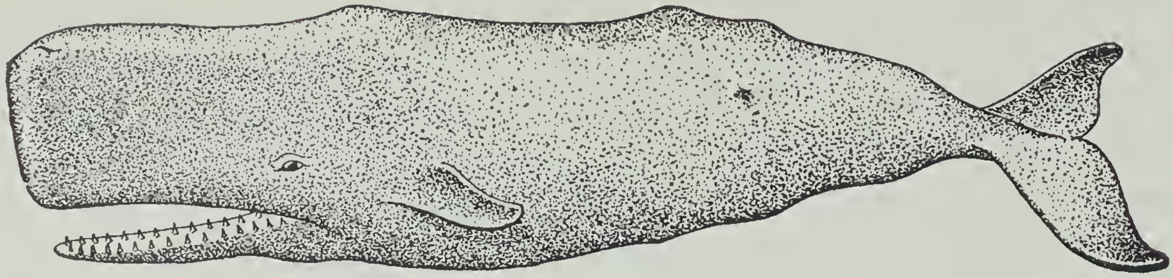

FIGURE 34. A sperm whale.

a half mile in diving. This ability is probably due to many adaptations of the whale's structure. Two may be mentioned. First, a layer of fat in the body wall protects the whale against the effects of rapid change in temperature and against cold. Second, a peculiar network arrangement in the whale's system of veins is believed to provide against the sudden release of dissolved gases from the blood when external pressure is relieved. Such an adaptation apparently makes it easier for an animal to go rapidly from a region of high pressure to a region of low pressure without suffering ill effects.

Deep-sea diving. The human body has no such special network of veins. Men who work in deep tunnels or in submarine diving may suffer from a condition called "bends" if they are brought up to the surface too rapidly. Under great pressure, nitrogen from the air will enter the blood in large quantities. This nitrogen is not used by the body but passes gradually into the tissues of the body from the blood. If the outside pressure is released suddenly, as in the case when a diver is brought up to the surface rapidly, the nitrogen gas will tend to escape from the body at a high rate of speed. This causes the blood to foam. Bubbles of nitrogen block the free passage of the blood in the blood vessels. Other bubbles may gather about nerves and cause paralysis or intense pain. In severe cases, death may result. This explains why deep-sea divers often are brought to the surface slowly,[1] allowing the body to adjust itself gradually to the changing pressure.

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[1] Or are put in decompression tanks after having been brought to the surface.

LIVING THINGS NEED OXYGEN AND FOOD

We have seen that both plants and animals must be supplied with food and oxygen. It is not surprising then that life is limited to those portions of the earth where food and oxygen are available. The upper part of the atmosphere provides little in the way of food materials and little oxygen. While all living things must have oxygen, not all need to get it directly from air. Fish, as we have noted, extract dissolved oxygen from water. Certain bacteria seem able to break down organic compounds and use the oxygen contained therein. Food may come from many and diverse sources, depending upon the food habits of the organism.

Organisms must have food. The food supply is seen as a varying factor in environment, which determines, to a large extent, the habitats and distribution of organisms. Why does coral grow chiefly on one side of a reef? Why do fish live near the shore? Why do hunters look for certain animals in definite places? How are we to control flies, bacteria, and other disease-producing organisms?

The answers to these and other similar questions may be suggested by a study of the food supply. Where there is no food there is no active life. Where food is plentiful and easy to obtain, life may be abundant. If you wish no mice in the pantry leave no food available. When your lawn does not look as green as your neighbor's or your garden beets have tops but no beets, your lawn and garden may need fertilizer.

In human relations too, the food supply seems to have determined the policies of nations. "Overpopulation" may be only another way of saying "an undersupply of food." Some economists and statesmen tell us that wars, territorial expansion, and policies of foreign trade are largely determined by the food problems of a people. The history of mankind appears to have involved many a struggle for food.

Food chains in the sea. The food relationships of sea organisms resemble those found among the inhabitants of fresh-water ponds. At or near the surface are light and air. Here the sea is teeming with small plant and animal forms that constitute what is called plankton (meaning wandering forms). This term also may be applied to similar small organisms found in fresh water. Most of these plankton organisms merely float or are carried by water currents at or near the surface. A few of them have swimming movements. There also are larger species of marine plants and the larger, familiar marine animals. In such a life zone the larger plants and the plankton furnish food for some of the animals. Other animals may feed partially or wholly upon smaller animals.

We have learned that green plants are dependent upon sunlight. We find then that living plants in the sea are confined to rather shallow water, into which sunlight penetrates. The majority of these plants live within one hundred feet of the surface.

Plants furnish food materials for the animals, and as plant life becomes scarcer with increasing depth, animal life also is less well represented. But the situation is somewhat different in the deep sea. Here the dead organisms from the surface have settled to the bottom. They furnish one source of food supply for the animals found in deeper waters. Thus in last analysis, we see that all animals in the sea, whether in shallow water or deep water, are dependent upon green plants for food supply.

Range of life. Viewed as a whole, then, life on this earth appears to be confined to the surface and to a relatively small distance above or below the surface. If we consider the extremes of altitude reached by aviators and the greatest known depths of the ocean, we can picture a comparatively thin layer, about ten to fifteen miles in thickness, in which life commonly exists.

TEMPERATURE IS AN IMPORTANT FACTOR IN THE ENVIRONMENT

Human body temperature. The range of temperature to which many organisms are adapted is relatively small. In the case of man, the normal average temperature of the body, measured by placing a thermometer in the mouth, is 98.6° F. However, this temperature varies somewhat with age. Also, there may be as much as one degree normal variation within a period of twenty-four hours. The body temperature normally reaches its highest point in the evening and is lowest early in the morning.

The foregoing statements refer to normal temperature variations in man. When the temperature rises above the normal variation, as it does in a number of illnesses, the victim is said to have a fever. In some other abnormal conditions, such as in cases of starvation, the body temperature may fall below the normal variation. Except in such diseased or abnormal conditions, however, human body temperature is fairly constant.

Cold-blooded and warm-blooded animals. In birds the normal body temperature is rather high, ranging from 102° F., to 114° F., or more. This is higher than the normal temperatures of man, the dog, or the cat. In birds, the daily variation is greater than in man. Animals such as man and birds are said to be warm-blooded. This is because they maintain fairly uniform body temperatures, regardless of the temperature changes around them.

FIGURE 35. A bird; an example of a warm-blooded animal.

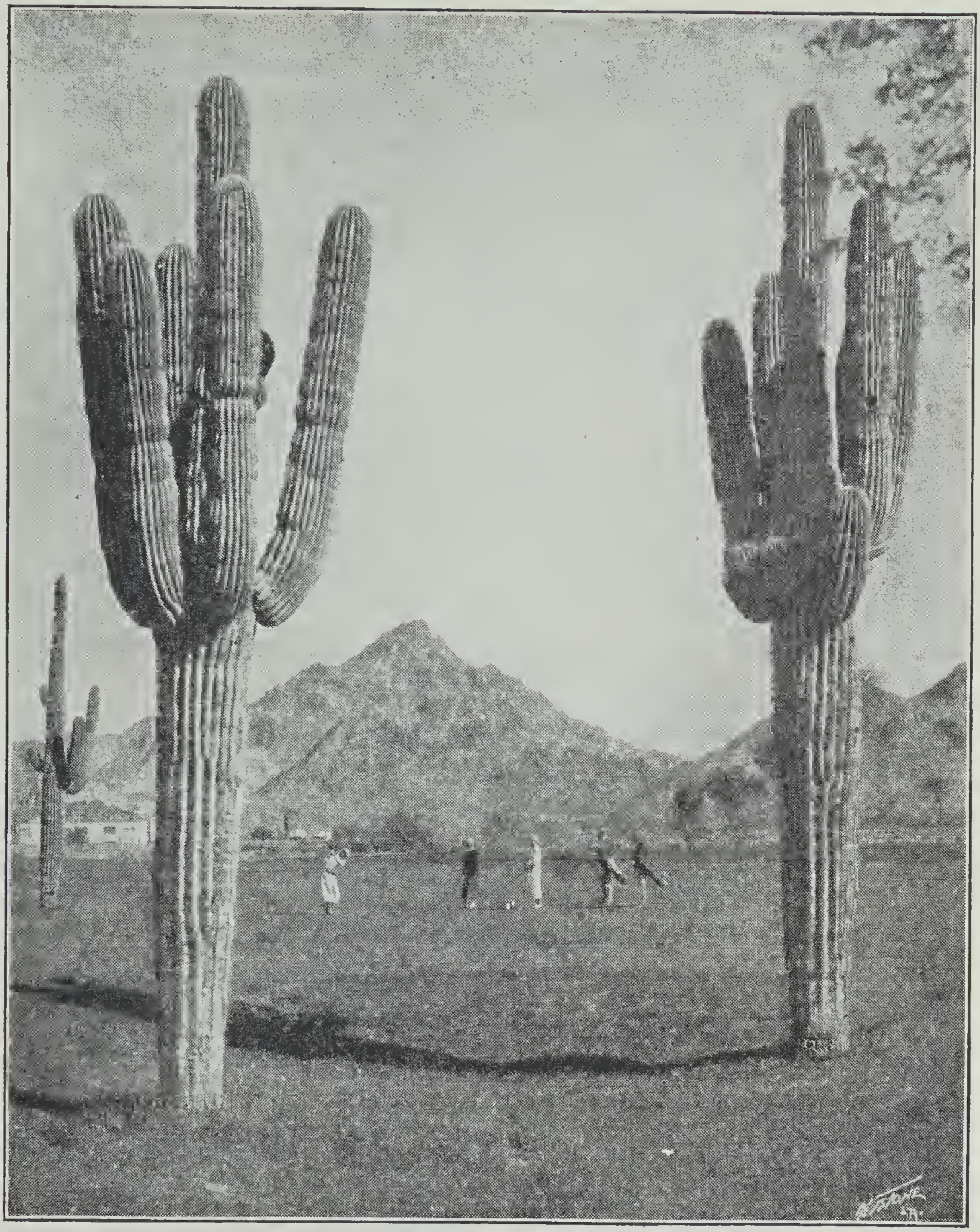
A great many animals vary in body temperature as the temperature varies in their surroundings. The body temperatures of a frog or a fish, for instance, will rise if the temperature in the surrounding medium rises. Or they will fall if the temperature in the surrounding medium falls. Such animals are said to be cold-blooded. Plants ordinarily have temperatures very nearly that of their surroundings. There are, however, certain exceptions; for example, a rise of temperature occurs during the sprouting of seeds.

Temperature and life. All life requires some degree of warmth. Activity definitely slows down when body temperature falls. Generally speaking, seeds do not sprout in freezing temperatures. Most bacteria do not grow readily in freezing surroundings. In our temperate zone the winter season is marked by a partial or complete resting period on the part of trees, grasses, and shrubs, and by the death of annual plants. In cold weather there are periods of inactivity in the lives of bears, woodchucks, ground squirrels, and many other animals.

It is common knowledge, however, that with the return of higher temperatures, following a cold period, many organisms which have been inactive will resume their normal life activities. For instance, we find that typhoid fever has been caused by the use of ice containing typhoid germs. Some protozoa, rotifers, and other animals will survive freezing, although they may be inactive at the lower temperatures.

Temperature and moisture. Increase of temperature also has its well-marked effects. When moisture is present, as in the swamps and rain-belts of the tropics, the hot weather appears to favor increased growth and luxuriance in the Plant Kingdom. It is often noted that a tropical jungle will spread over an abandoned city or clearing within a relatively short period of time. In desert regions, of course, we find only cactus, sagebrush, and similar vegetation, or no vegetation at all. But this may be a result of the lack of water rather than unfavorable temperatures.

The proof that many desert regions may support life is shown by the growth of both plants and animals at water holes or oases. We also know that some of the greatest yields of garden vegetables are obtained in reclaimed desert or arid regions. Here water has been brought by a system of irrigation canals and ditches from distant sources. Such regions are found in California, Utah, Arizona, Colorado, and other localities.



Ewing Galloway, New York.

FIGURE 36. An Arizona golf course — note the giant cacti. How are such cacti adapted to their desert environment?

When given sufficient moisture many species of plants thrive best in hot weather. Brown, withered grass, or failure of crops in drought may be results of not enough water supply rather than too much heat.

Perspiration. There are upper limits of favorable temperatures, however. Sunstroke is well known among human beings. Dogs, horses, hens, and other domesticated animals are visibly affected on days when the temperature of the air is above 90° F.

Experiments have shown that when the temperature of the air is about 68° F., the human body, at rest, loses to the air about the same amount of heat as is produced by activities within the body. Below this temperature, the body loses heat to the air faster than it is produced.

At higher temperatures, the body cannot dispose of the heat produced within, without resorting to the mechanism of perspiration. Moreover, the amount of moisture in the air and the movements of the air are important factors. For if the air is full of moisture (high humidity), the perspiration cannot evaporate from the body rapidly, and this outlet for excess heat is not effective. This is one reason why we feel uncomfortable and drowsy during hot, "muggy" days of August.

On the other hand, heat is lost faster and evaporation of perspiration increased when the air in contact with our bodies is constantly replaced by other air. This principle is well illustrated by the practice of moistening a finger and holding it up in the air to determine the direction of the wind. The finger feels colder on the side on which the wind blows because of more rapid evaporation there. The use of fans, and the popularity of sports such as motoring and motor-boating, which produce the effect of a breeze, should be thought of as practical aspects of this principle of body heat adjustment.

Pasteurization. Other organisms withstand varying degrees of high temperature for longer or shorter periods. One type of milk "Pasteurization," in which process the temperature is maintained between 142° F., and 145° F., for thirty minutes, destroys many bacteria, including disease-producing types. Yet some bacteria survive even this heat. The precise upper limit of temperature at which any life can exist is not known. Most known forms of life are destroyed when or before the boiling point of water (212° F.) is reached. Above this temperature few organisms survive. Destruction of microscopic organisms by boiling, baking, burning, or through the use of chemicals, is called sterilization.

WATER IS NECESSARY TO ACTIVE LIFE

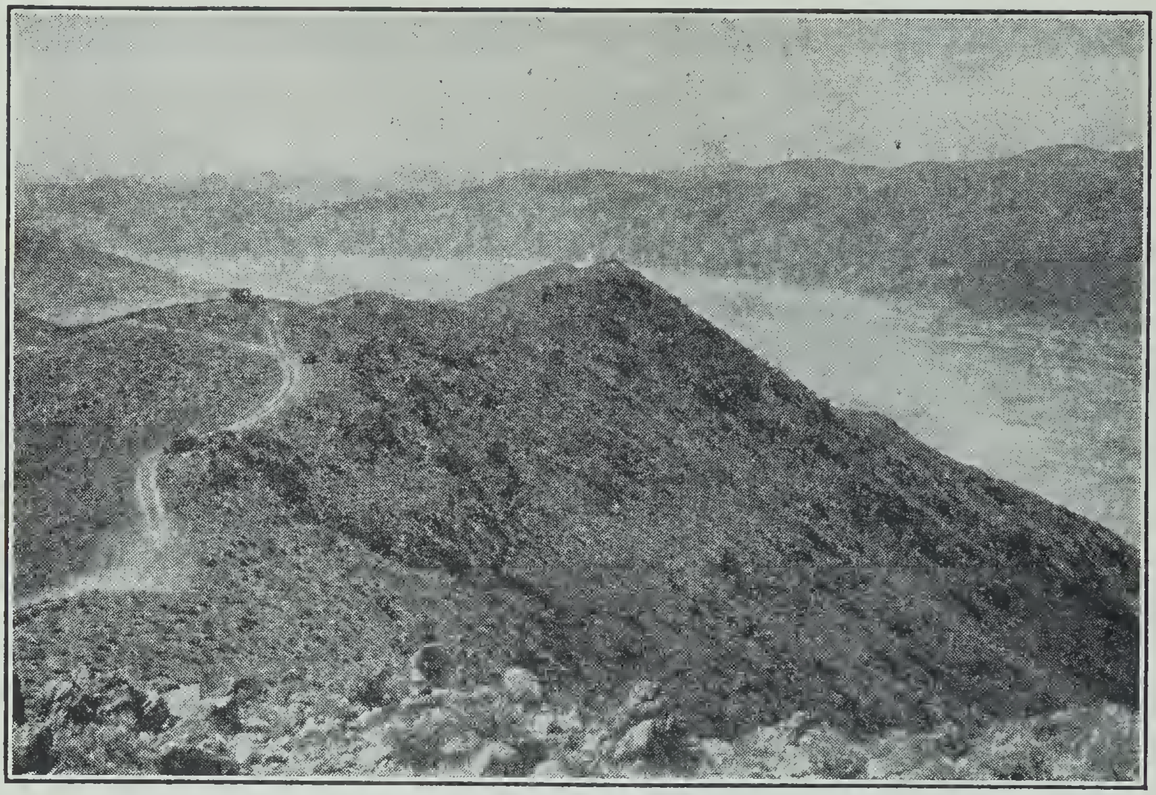
That water forms a large part of living substance is well known to all of us. We have observed the shrinking of apples, apricots, and potatoes as they become dry. We are familiar with the difficulty in burning many kinds of freshly cut or "green" wood. We know that if such wood is allowed to stand until it is dry it will usually burn much more readily.

Water in living materials. A simple experiment that may be made in the laboratory or at home is to weigh a whole potato and then cut it into pieces and place the pieces, spread out on paper, near a radiator. Leave them for a few days and then weigh them again. The loss of weight represents the water that has evaporated. To determine the percentage of water more accurately, however, we should dry the pieces of potato in an oven. The drying should be continued until repeated weighing tests show that no further loss of water has occurred.

The percentage of water in different organisms and parts of organisms varies, as may be seen from the following examples:

	Per cent water
Lean meat	70
Hen's egg	74
Milk	86
Potatoes	75
Beets	87
String beans	89
Spinach	92
Lettuce	94
(Human body)	65

The presence of this high percentage of water in natural foods is recognized by hunters and marching troops who use dehydrated foods. These are foods from which the water has been evaporated at low temperatures. Such foods retain their flavors and food values, but weigh much less than the natural foods.



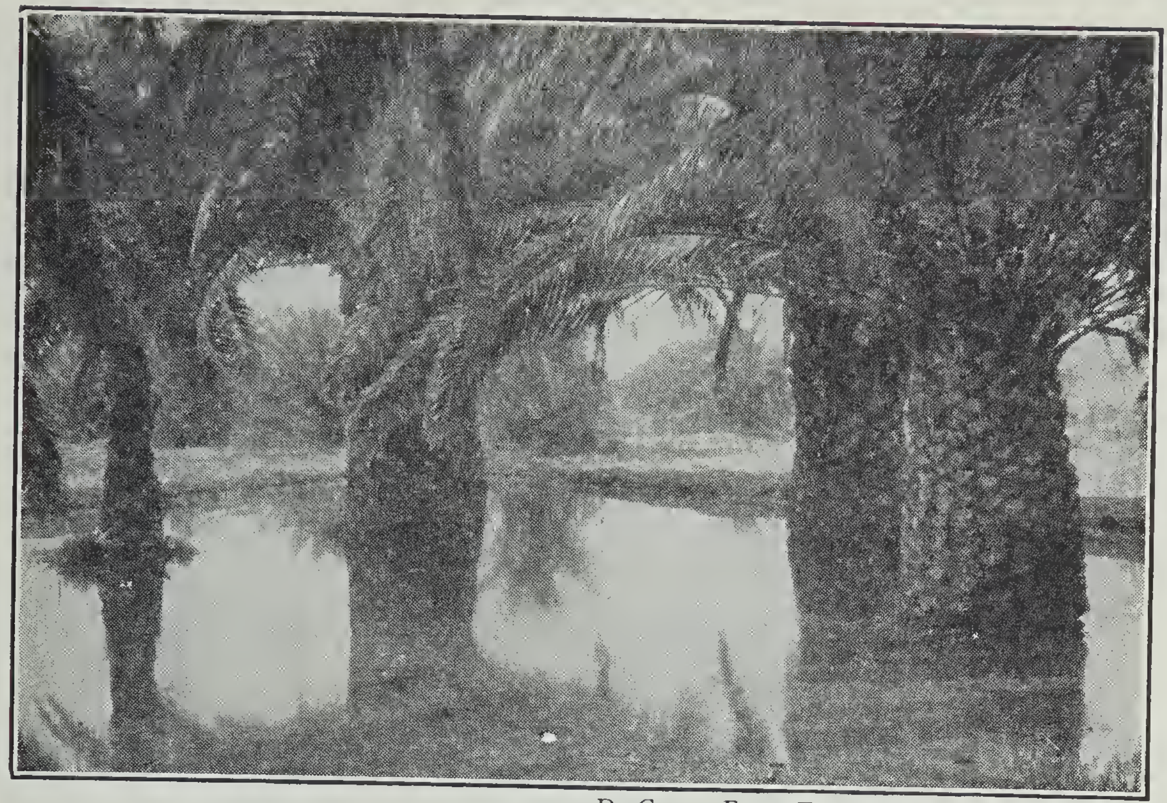
Ewing Galloway, New York.

FIGURE 37. A scene in Death Valley, California. Death Valley is noted for its aridity, high temperatures in the summer, and low temperatures in the winter. Note the absence of larger plants such as trees.

The difference in weight represents the water that has been removed from them.

Animals commonly drink water or take it with their food. Many plants absorb water through their roots, and in some cases through their leaves and stems. Some animals, such as camels, can go for a long time without drinking. These animals have special adaptations for taking large quantities of water at one time. Rabbits seldom appear to drink. When we consider that their food is chiefly watery plants, such as lettuce, clover, and grass, we cease to wonder. Hunters take advantage of the need of wild animals for water by lying in ambush at water holes, or on mountain runways by which the animals travel to water.

Adaptations of desert plants. As we already have pointed out, the absence of life on deserts may be due to lack of water rather than to excessive heat. Typical desert plants such as cacti do not have broad leaves like those of a sunflower or an elm. Such



De Cou. From Ewing Galloway, New York.

FIGURE 38. An oasis in the desert — Furnace Creek Oasis in Death Valley, California.

broad leaves would provide too great a surface for evaporation. In their absence the plants are able to conserve their water supplies. The life activities that normally would be performed by the leaves are provided for by the stems of the cacti. Thus it is possible for these plants to retain moisture from one short, rainy period through the long, hot, dry months when most vegetation would perish.

Seeds of many plants, when properly dried, may remain dormant for years, but may sprout readily when put in moist earth. Many small organisms, such as some bacteria and protozoa, can survive drying for long periods of time. They may become active again when returned to moist surroundings. The higher organisms usually have less ability to adapt themselves to variations in the water content of their environments.

Summary. We see, then, that most living things are found on or near the surface of the earth. Some species, to be sure, are found at high altitudes, or in the deep sea. These species have special adaptations which enable them to live in such habitats. Extremes of pressure and temperature usually are not favorable to life. Oxygen and food are among the necessities of life. Water makes up a large part of protoplasm — it also is necessary to active life. These factors of the environment are of great importance. They have great influence upon the behavior and the geographical distribution of organisms.

SUGGESTED ACTIVITIES

Scientific methods

(*a*) A scientist makes controlled experiments, and records the observed facts.
(*b*) A scientist considers the source and the accuracy of facts reported by others.

1. After consulting the reading references at the end of this chapter, prepare a report on "the adaptations of animals living in the deep sea."
2. Using a watch, determine the number of times each pupil in the class inhales per minute when sitting quietly in a chair. Compute the average per minute for the class. Assuming that thirty cubic inches of air are taken in at each inhalation, and that one and one half cubic inches of oxygen are retained by the body, how many cubic inches of oxygen are used by the average pupil per minute? Per hour? Per day?
3. After consulting the reading references at the end of this chapter, prepare a report on the food of the following organisms which live in the shallow sea: algæ, sponges, corals, clams, lobsters, and one or two species of fish.
4. After consulting the reading references at the end of this chapter, explain how the human body maintains a fairly constant temperature (*a*) when the outside temperature is low, and (*b*) when the outside temperature is 90° F.
5. Which would you expect to contain the larger percentage of water, an apple or a potato? Why? Plan and perform an experiment to determine the facts.
6. Plan and perform an experiment to show the relationship of water to the sprouting of seeds.
7. Self-testing exercise. Which word in the left-hand column is most appropriate for each statement in the right-hand column?

1. Sterilization
2. Geographical distribution
3. Perspiration
4. Pasteurization
5. Adaptation

1. Destruction of small organisms by boiling or through the use of chemicals.
2. Process by means of which the human body discharges excess heat.
3. Refers to the places where a plant or animal is found.

SUMMARY OF PRINCIPLES

1. A preliminary survey of the distribution of life reveals living forms adapted to all the zones of the earth, on the land, in the sea, and in the air.
2. Most life is found on or near the earth's surface. Life does not appear to exist extensively at high altitudes or deep in the rocks of the earth.
3. Extremes of pressure are limiting factors of life.
4. Moderate temperatures are favorable to life.
5. Animals are grouped on the basis of their temperature adaptations in two classes, the cold-blooded and the warm-blooded.
6. Other conditions necessary to active life are the presence of water and oxygen.

GUIDE QUESTIONS

1. What is meant by: (*a*) tree line, (*b*) snow line?
2. What types of living things are found in the soil?
3. What conditions of light, temperature, and pressure exist at the bottom of the ocean?
4. Why is green plant life found only near the surface of the ocean?
5. How do organisms at great depths in the ocean get food?
6. What is "plankton"?
7. What is the "normal temperature" of the human body?
8. At what external temperature do human beings feel the least discomfort? Name other factors which may be involved.
9. Mention two cold-blooded animals and two warm-blooded animals.
10. What is Pasteurization? Sterilization?
11. State one or more facts which give evidence that excessive heat is not the cause of the scarcity of life in all deserts.
12. What is the percentage of water in: (*a*) the human body, (*b*) milk, (*c*) spinach?

BOOKS TO READ

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CHAPTER IV

THE CHANGING ENVIRONMENT

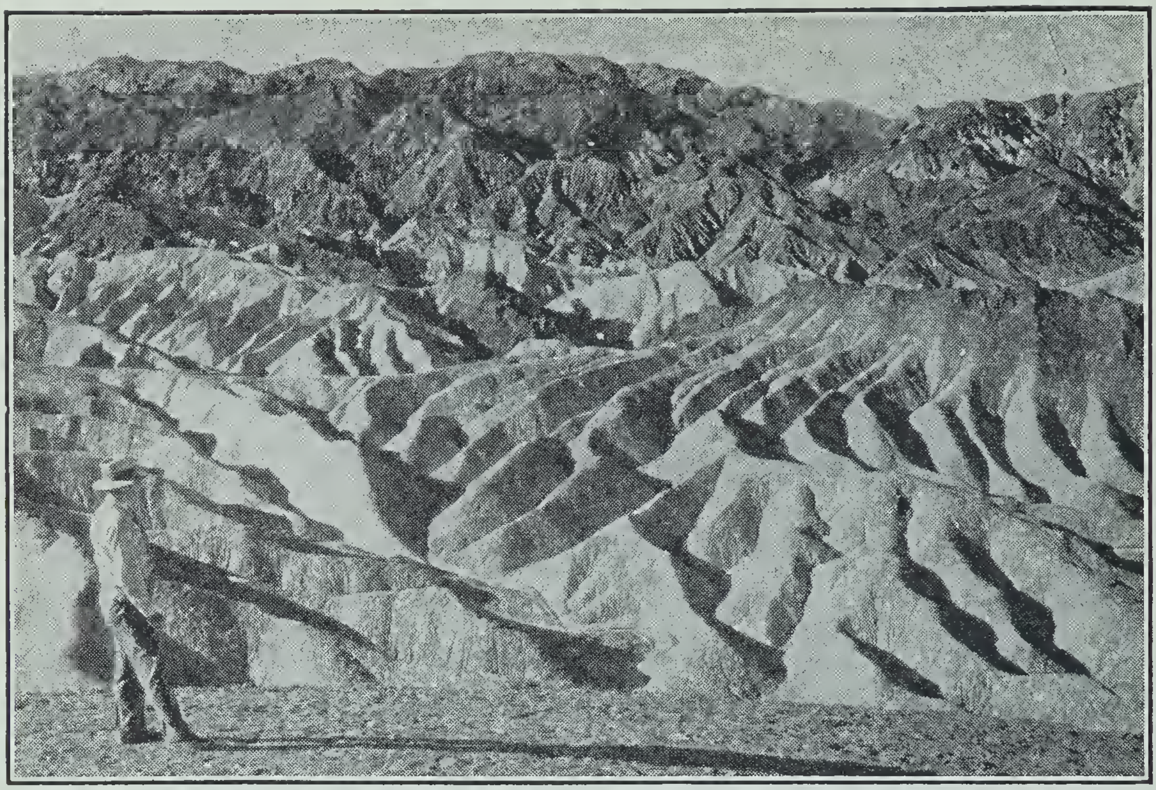
Problems:

1. Do changes occur in nature?
2. How does the study of rocks inform us about the past history of the earth and its inhabitants?
3. What changes may be observed in modern times?

ENVIRONMENTS CHANGE

Foreword. The preceding discussions have been concerned with organisms and their environments. We have seen that plants and animals have more or less definite habitats, and that they may possess adaptations which enable them to live in these habitats. Yet we cannot avoid observing that conditions within a region undergo changes. What effects do these changes have upon life?

Changes in nature and culture. When Hendrik Hudson, in 1619, discovered the river which bears his name, Manhattan Island was covered with forests. Today, the incoming visitor sees a skyline of great buildings. When the Union Pacific Railroad was completed in 1869, great herds of bison roamed the plains. Painted Indians curiously watched the "white man" build the roadway for his "iron horse." Today, bison are limited to a few carefully protected herds, and to public parks. The Indians have largely adopted the white man's clothing, and ride on the railways. No fact is more certain than that everything about us is constantly changing. Yet often the most obvious things in our lives are the ones to which we pay the least attention. The seasons come and go. We go to school, to college, and into the business or professional world. About us buildings are erected, others torn down. Forests are destroyed; new forests grow. Tides rise and fall. Periods of prosperity and depression succeed one another. Nations go to war and make peace.



De Cou. From Ewing Galloway, New York.

FIGURE 39. Soil which has been worn away (eroded) by running water. Running water causes great changes to occur upon the surface of the earth. What becomes of the soil which is washed away?

It is the purpose of this and the following chapter to outline some of the changes that have taken place during the past, and the development of organisms amid the changes.

THE EARTH HAS A LONG HISTORY

Copernicus. Strange to say, many of our beliefs about the history of the earth have resulted from looking at other objects out in space. Astronomy, which is the study of such matters, is a very ancient science. But up to the time of Copernicus in the fifteenth century, the prevailing idea pictured the earth as a flat, round disc. Copernicus asserted that the earth was a sphere, and that the apparent rising and setting of the sun resulted from rotation of this sphere.

Galileo. Use of the telescope in studying astronomy was begun by Galileo during the seventeenth century, although he was not the first to invent an instrument that would magnify distant objects. Today, with the aid of larger and more powerful telescopes than Galileo possessed, we can see far off into space. We study suns, planets, and the hazy masses of material known as nebulæ.

The solar system and the universe. Our earth is a spheroid, one of several spheroids that are moving about the sun in elliptical pathways. The other eight, together with the earth, are called planets. The pathway of the planet that is farthest from the sun (now believed to be Pluto) marks the limit of our solar system. But our solar system occupies only a small part of the universe. The stars, for example, are in reality great masses of hot gas; that is, suns like our own. These suns may be centers of other solar systems. Every new and more powerful telescope discloses other stars beyond those that we saw before. Probably the universe is vastly larger than we can comprehend.

Age of the earth. Early astronomers and geologists made various attempts to explain the origin of the earth, and made estimates as to its probable age. Such theories and estimates have been based upon the study of nebulæ, stars, and our solar system, and upon the study of rocks. From time to time it has become necessary to revise estimates of the earth's age in the light of newly acquired knowledge. Geologists now think that the earth must be very old, in order to account for changes in the rocks that have occurred since they were formed.

Whatever may have been the origin of the solar system and the earth, there is no doubt that the latter began its career millions of years ago. During an early stage of origin the earth may have been composed of hot, gaseous materials. Or more probably a combination of gaseous, liquid, and solid substances. Probably some of these materials cooled and condensed, gases becoming liquids and eventually solids in some cases.

At an early stage in the earth's history we can picture a solid outer crust, surrounded by great clouds of vapor. The vapor would cool, condense, and produce torrents of rain. Mountains and hillsides would be scoured by running water, and their materials would be washed downward into the valleys, rivers, and seas. The evidence of the rocks tells us that at various times there have been readjustments of the earth's substance. Areas of land have been raised above sea level, and in some cases folding of the earth's crust has resulted in the formation of mountains. There also have been long periods during which land areas and mountain ranges have been worn away by the action of running water and other forces. Needless to say, such extensive changes can occur only over long intervals of time.

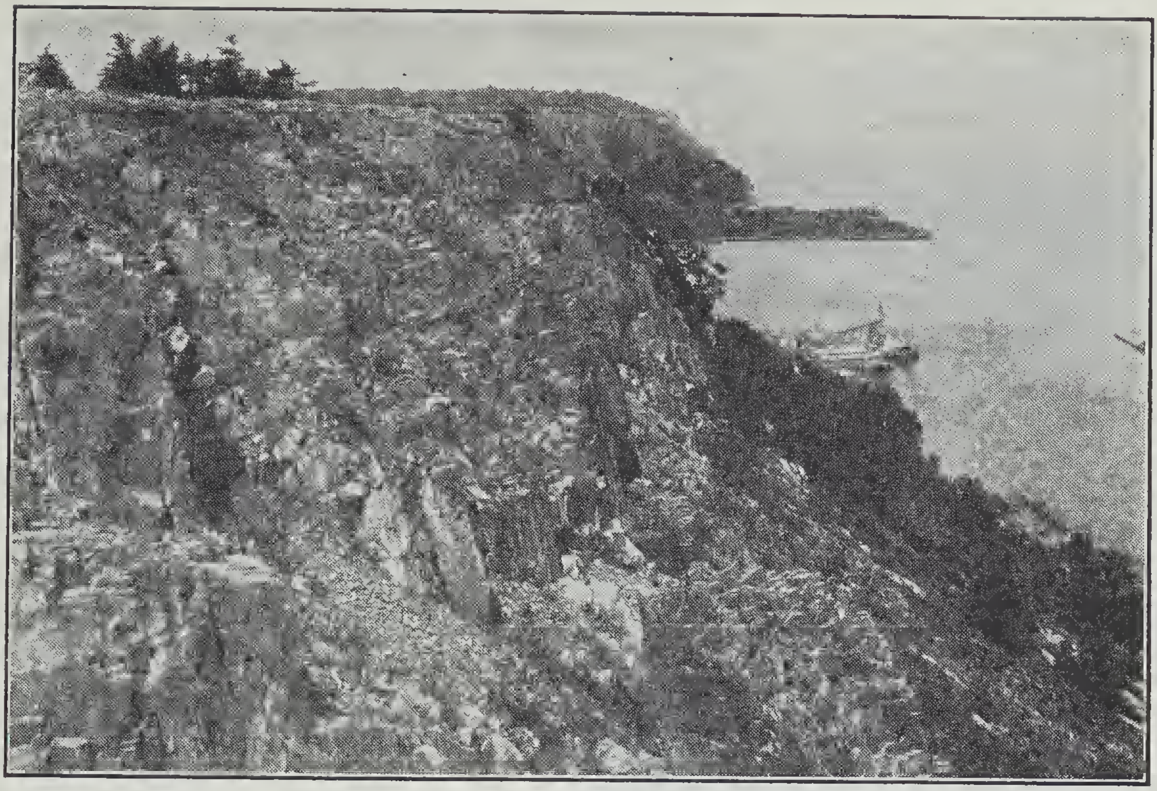
What are rocks? Someone has said that the pages of the book of earth history are the rocks. To understand this statement let us see what rocks are. If you dig into the earth anywhere you eventually reach bed rock. On mountain sides and in the beds of streams this bed rock often is exposed to our view. Examination with a lens and by chemical means reveals that practically all of the chemical elements enter into the composition of rocks of one kind or another. The word rock, then, is a general label for any kind of hard substance making up the solid part of the earth. Bed rock is the underlying rock attached to the interior of the earth.

Many of the rock layers which form the earth's crust were laid down before man was in existence. Our knowledge of their origins is based upon:

1. Examination of their structures.
2. Experimentation, by which similar rocks are made artificially.
3. Observation of natural forces now at work forming rocks.

Igneous rocks. Sometimes it is possible to observe the flow of molten lava from a volcano. This lava cools after it has poured forth over the surface, and becomes solid rock. There is much evidence that many rocks, such as granite and basalt, have been formed through the cooling of liquid materials. Such materials may be forced up between older layers of rock, or they may spread out over the surface. When cooled they form the igneous rocks.

Erosion and soil formation. Rocks on the land are gradually broken up and worn away by wind, water, freezing and thawing, and other factors. These rocks contain various materials which



From Ewing Galloway, New York.

FIGURE 40. The Palisades of the Hudson, composed largely of igneous rock.

are substances of definite chemical composition. Granite, for instance, may contain the minerals feldspar, quartz, hornblende, and mica. Some minerals may be dissolved out of the rocks by surface or ground water. Other parts of the rocks may be broken down to form sand and clay. Clay, sand, and the organic remains of plants and animals mingle to form soil. These processes, which result in the wearing away of rocks and eventually of soil, constitute what is called erosion.

Sedimentary rocks. Rivers carry soil to the ocean. Here the soil settles to the bottom as beds of mud or sand or both, sometimes mixed with the lime skeletons of dead sea animals. As this material accumulates, it becomes pressed together into layers of sedimentary rock. Such rock may be sandstone or shale (from mud) or limestone, or mixtures of these three substances.

Metamorphic rocks. Still another class of rocks appears to be formed from other rocks which have been subjected to great pressure or to heat or to both. Examples of this type are gneiss, which contains the same minerals as granite; slate, which is chemically the same as clay or shale; and marble, which is developed from limestone. These are called metamorphic rocks.

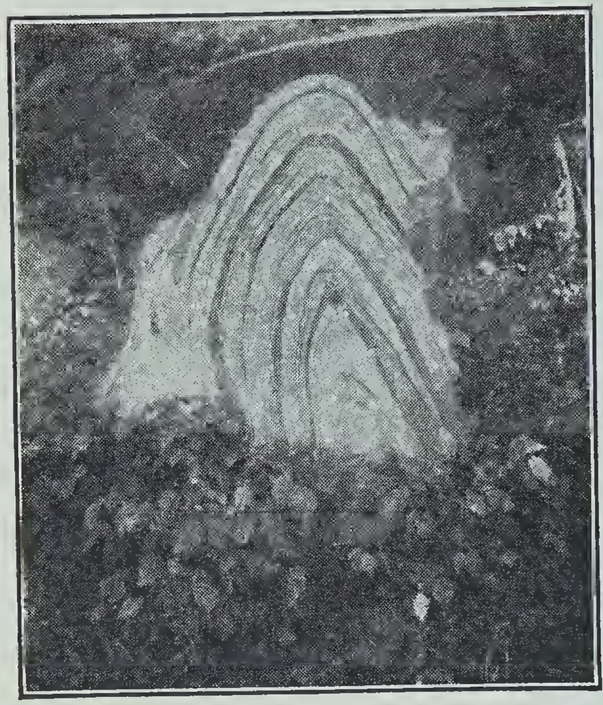


FIGURE 41. Gneiss, showing folded layers of the rock.

Age of rocks. In some places the layers of rock have been formed one on top of the other, often with long periods of time between the formation of two successive layers. It would appear that the top layers should be most recent in age. The lower layers should be most ancient. Remains of plants and animals found in the upper layers should be more recent in origin than such remains from the lower layers.

Of course in many places the record of the rocks has been disturbed greatly by the weathering away or erosion of entire layers. Or the original layers have been broken up by folding of the earth's crust or by volcanic activity. Only careful study by trained geologists has revealed locations where the original layers have remained more or less undisturbed. This in turn has enabled biologists to read the record of life in successive stages of the earth's history.

It also is possible to estimate the time interval represented by a certain thickness of sedimentary rock. Formerly, geologists made this estimate upon the basis of the time in which a deposit of such thickness would be formed under conditions existing today. More recently it has been found that chemical changes, particularly radioactivity, proceed at a definite rate in certain rocks. By measuring the amount of chemical change that has occurred in a given rock, it is possible to estimate its age. We learn that some of the oldest rocks evidently have been in existence for nearly 2,000,000,000 years. Using such evidence, Sir William Rutherford has estimated the age of the earth to be about 3,000,000,000 years.

FOSSILS ARE RECORDS OF PAST LIFE

Formation of fossils. The formation of sedimentary rocks goes on most actively in the shallow sea, where rivers are discharging their loads of sand and mud. Many organisms have lived in this shallow sea for countless ages. The dead bodies of some organisms became buried in the sediments. Here they did not decay as rapidly as they would have done if fully exposed to the actions of air and bacteria.

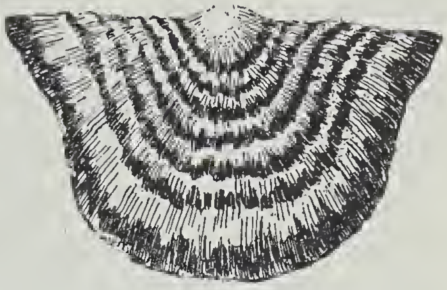


FIGURE 42. Diagram of a fossil brachiopod.

Instead of decaying, some of the shells of ancient clams and similar forms of life, woody tissues of plants, and some of the skeletons of fish and crustaceans were preserved for a time. Then the original materials were dissolved away bit by bit and were replaced by harder materials in some cases. In other cases only impressions of shells, leaves, or footprints originally made in the mud, have been preserved. Such evidences of past life are called fossils.

Not all fossils were formed in the shallow sea. Some have been preserved in river deposits, some in swamps, some in tar pits, some in the form of petrified forests, or in the form of land deposits. Coal really is a fossil material, since it is formed from plants that become buried in the mud and water of swamps. Occasionally the imprints of ancient leaves, or fossil remains of trunks and branches of trees are found in layers of coal. Fossils are found commonly in many deposits of shale and limestone. Thousands of them, representing many different types of plant and animal life, have been collected in various widely separated parts of the world. They tell us the story of life in past ages, before the dawn of written history.

THE RECORD OF THE ROCKS INFORMS US OF MANY PAST CHANGES IN ENVIRONMENT

When we examine some layers of rock in what is now the Mississippi Valley, at least a thousand miles from the sea, we find that they contain many fossils. Some of these are fossils of fish, some represent crustaceans, and some the skeletons of other animals such as crinoids. But all of them are sea-dwelling types. The suggestion plainly is that at one time this region must have been covered by the sea. Similar evidence of the former presence of shallow seas on what are now land areas may be seen in many places.

Changes in climate. Geological research tells us that the Rocky Mountains are of comparatively recent origin. Before they were formed, much of the interior of what is now the United States was covered by shallow seas and swamps. This is indicated by the presence in this region of sedimentary rocks containing the fossil remains of sea animals, and by the presence of coal beds in some places. Some of the plants represented in the coal are tropical types, which suggests a much warmer climate in the past than is found in this region today. Deposits containing fossils of semi-tropical plants are found as far north as the Arctic Circle.

Various theories have been advanced in attempts to explain the changes in climate which have occurred during geological history. In any case, we know that effects result from causes. We see the effects of change in the form of fossils — fossils of subtropical plants in far northern regions. How could they have existed there? Probably because they were receiving more solar radiation (sunlight) than would be the case at the present time. We have learned that solar radiation furnishes the energy necessary to food making by green plants. We would expect an average increase of solar radiation to be accompanied by an increase in the growth of many plants, provided that other conditions of life were favorable. An increase in solar radiation would produce an extension of tropical and subtropical areas into what now are temperate zones. We could expect that many living things would respond to such changes.

The glacial period. Most people have heard some reference to the last great glacial period.[1] In terms of geological time this period ended rather recently; in fact, some geologists have suggested that it may not be ended. During this period, five great glacial sheets of ice moved southward across North America. The ice sheets moved well into the area that is now included in the United States. These five invasions of the glacial ice sheets were separated by periods during which the climate evidently was milder.

The widespread glaciers of this glacial period left their marks upon the land and produced great changes in the plant and animal life of North America. For instance, many glacial boulders, U-shaped valleys, ponds, and lakes owe their origins to these glacial invasions. The glaciers brought with them vast quantities of gravel, sand, and soil, which remained behind when the ice sheets melted away. Various animals no doubt were driven southward by the successive advances of the ice. Some species of plants and animals were no longer able to survive in their former northern homes when the climate became colder. Probably at such times the average amount of solar radiation was reduced. Many species which had lived before the Pleistocene became extinct during that period.

From the foregoing examples we see that one kind of change through which the earth has passed is change in climate. Mild periods have alternated with periods during which the climate was cold. There is abundant evidence that climates of many regions — perhaps all regions — have undergone marked changes.

Erosion of mountains. Our modern mountains are being worn away by the forces of erosion. When we study the present height of mountains and the slope of their folded rock layers we can make estimates as to their original height. Thus the Appalachian Mountains of the eastern part of the United States show great layers of rock folded in such a way that the upper parts of the folds must have provided for mountains over four times as high as those which remain today.

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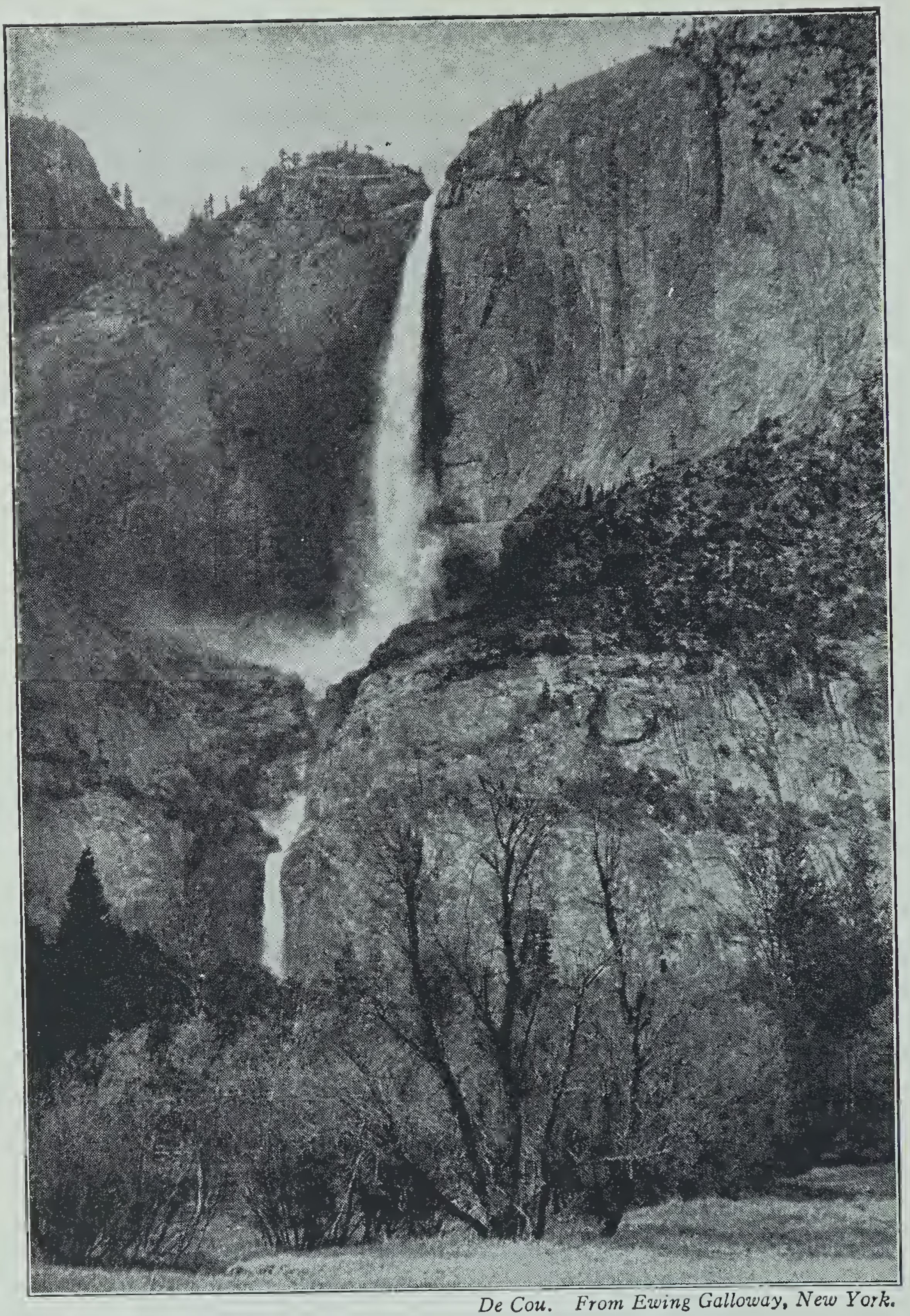
[1] The Pleistocene Period.



De Cou. From Ewing Galloway, New York.

FIGURE 43. Yosemite Falls; Yosemite National Park, California.

Ancient lakes. At one time in the geological past two immense lakes existed over areas that are now plains. In places the old shore lines of these lakes may still be seen. One of these ancient lakes, given the name Lake Bonneville, existed in the region about Great Salt Lake in Utah. The other, called Lake Agassiz, covered a large part of what are now the states of Minnesota and North Dakota, and a part of Canada. Its modern remnant is Lake Winnipeg and the valley of the Red River. Some of the best wheat-growing land of this continent is found in the soil that formerly was a part of this great lake bed.

Many changes have occurred in the past. We now have considered some of the changes in environment that have been recorded in the rocks. We see that igneous rocks, wherever they are found, suggest the former presence of heat. Sedimentary rocks, containing the fossils of sea animals, tell us that great seas once covered some modern land areas. We are able to estimate the age of some rocks. The fossil record informs us of species that have lived for a time but have long since become extinct. Upon a number of occasions various portions of the earth's crust have been folded or raised above sea level, to be gradually worn away again by the action of erosion. In all cases we find that the story is one of change.

MODERN CHANGES MAY BE OBSERVED IN MANY PLACES

River deltas. Many of the changes that began in the past are continuing in modern times. Mountains are wearing down and the sediments are being carried by rivers to the sea. The deltas at the mouths of such rivers as the Mississippi are made up of sediments. Practically the whole state of Louisiana has been built up in this fashion and therefore the soil includes materials from both the Rocky Mountains and the Appalachian Mountains.

Volcanoes. Volcanoes in our own time pour lava over great areas of land, filling up valleys, changing the courses of rivers, and forming new islands. The Hawaiian Islands represent the craters and slopes of volcanoes. The state of Oregon is part of a former plateau of volcanic origin.

Coral reefs and islands. Coral reefs and coral islands have been formed in the past and are being formed today. A colonial type of coral, which is a simple animal belonging to a group known as the cœlenterates, establishes itself on the bottom of a shallow, tropical sea. It soon produces other individuals which form a colony. The colony grows as various individuals produce buds and the buds become new members. Each coral has a lime skeleton, and all of the skeletons are connected. As the growth of the colony continues, the older members become covered over, and die. Their skeletons remain to support the growth of the newer generations. Gradually a colony becomes larger and approaches the surface of the water, becoming a reef. Further growth may raise portions of the colony above the water for a short distance, if the individuals are washed by the waves that bring them food in the form of microscopic organic material.

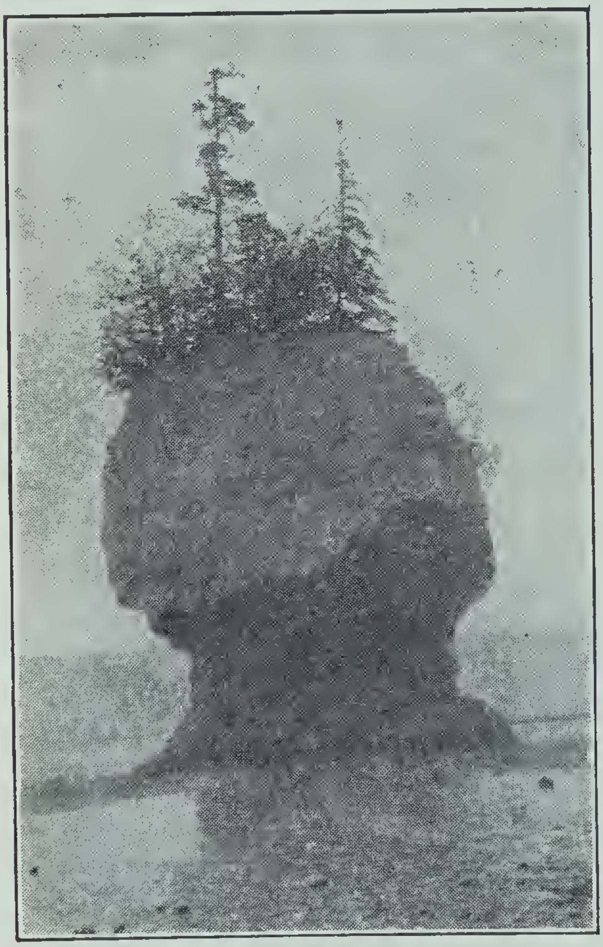


FIGURE 44. Pinnacle of rock resulting from wave erosion. (Courtesy of Professor H. J. Arnold.)

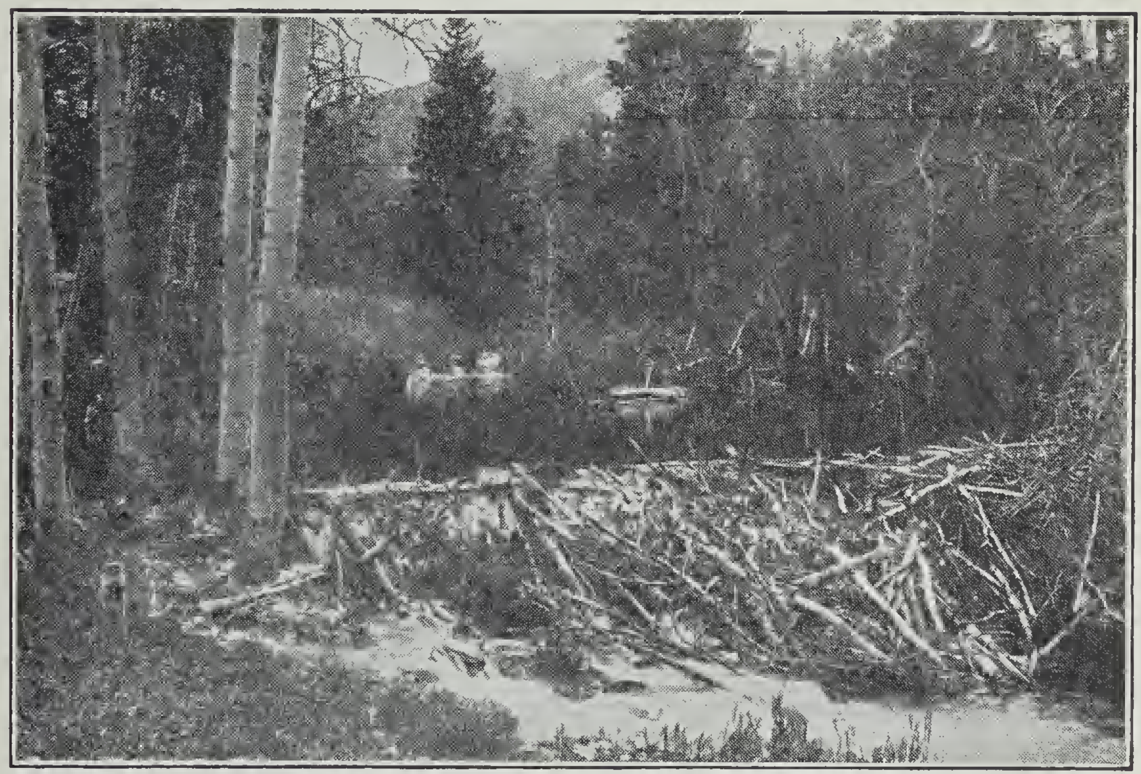
The coral island now becomes a possible habitat for terrestrial plants and animals. Sooner or later seeds of plants are carried to it by the water. It may become the habitat of some birds and insects.

Changes in land areas. Earthquakes have changed the height and shape of the land in various parts of the world within historical time. Glaciers may be observed in some mountainous areas and there are some very extensive glaciers in the polar regions. As a glacier moves, it erodes the soil and rocks over which it passes.

Sand and water marks on portions of our eastern coast indicate that the coast line once was farther inland. Along the New Jersey coast there are places where stumps of trees are now beneath the sea. This suggests that the shore line recently has been pushed inland. Thus portions of the land along the eastern coast have been both higher and lower than their present levels.

Niagara Falls. Every year erosion by the running water changes the position of Niagara Falls. The falls are gradually moving toward Lake Erie. The gorge or canyon below the falls has been cut out of solid rock by the forces of erosion. This gorge now is over seven miles in length. Surveys have shown that it is working its way toward Lake Erie at an average rate of over four feet per year.

Beaver dams. If you have an opportunity to see a beaver dam, note how a pond has been formed by backing up of the water. Perhaps it may be noted that trees which were on the land before the dam was built, are now in the water. Probably



De Cou. Copyright by Ewing Galloway, New York.

FIGURE 45. Beaver dam and pond. The building of beaver dams changes the environment of many organisms.

many of these trees will be dead or dying. Other terrestrial plants also fail to survive in the flooded area. Their places are taken by aquatic plants which flourish in the shallow water.

Changes occur all about us in the modern world. Even though you live in the city, you may see in the parks many examples, on a small scale, of changes in the surface of the earth. These are brought about by the actions of water, freezing and thawing, heat, gravity, and the growth of plant roots. Changes in the environment, then, are going on all about us. They have occurred throughout the history of the earth, and we see them taking place in the modern world. In spite of these changes, life has persisted. But many former species of plants and animals have become extinct, probably because they could not make suitable adjustments to changing conditions of life. Among the species that have persisted is man. In the next chapter we shall review man's career in a changing environment.

SUGGESTED ACTIVITIES

Scientific methods

A scientist makes use of drawings and diagrams to express his ideas, and to represent objects.

1. Make a trip into the field to observe changes in the environment. Note the erosion of soil and rocks by running water and other agencies. There may be opportunity to observe that individual plants and animals have died, and that young individuals are in the process of development and growth.
2. Collect samples of rocks from several regions, or observe samples in a school collection. Identify sedimentary, igneous, and metamorphic types.
3. After consulting the reading references at the end of this chapter, prepare a report on the formation of fossils.
4. After consulting the reading references at the end of this chapter, prepare a report on the glaciers of the Pleistocene Period, and their relationship to plant and animal life during that period.
5. Demonstrate how running water erodes an artificial pile of earth or sand, and how "fans" of sediment are formed at the base of the pile.
6. Prepare charts to illustrate the formation of gorges, canyons, deltas, and the filling of a swamp.

7. With the aid of your instructor, plan and carry out a study of some locality, planned to emphasize daily or weekly changes in the environment.
8. Which of the following responses is most appropriate for each item:
    a. The process of wearing away land areas is known as (1) erosion, (2) vulcanism, (3) climatic change, (4) fossilization.
    b. Environments (1) rarely change, (2) change continually, (3) are always favorable, (4) are always unfavorable.
    c. An evidence of prehistoric life preserved in the rocks is a (1) cyst, (2) parasite, (3) glacier, (4) fossil.
    d. The evidence from the study of geology indicates that climates (1) have remained about the same throughout time, (2) have been uniformly mild, (3) have changed from time to time, (4) have always been favorable to the success of plants and animals.

SUMMARY OF PRINCIPLES

1. The environment is in a state of constant change.
2. The earth is a part of the solar system and the solar system is a small part of the universe.
3. The history of the earth is recorded in the rocks.
4. From the record of the rocks we know that the earth is very old; perhaps 3,000,000,000 years.
5. We learn about prehistoric life from the study of fossils.
6. The record of the rocks indicates that the environment has changed greatly during geological time.
7. Many changes in environment are going on in modern times.

GUIDE QUESTIONS

1. Mention five changes in the conditions of your community that have occurred within two years.
2. Mention five changes that you have observed in the natural surroundings within a radius of ten miles from your home.
3. What is meant by the terms "solar system" and "universe"?
4. Name the three classes of rocks on the basis of their origin.
5. Where are rocks being formed today?
6. What substances combine to form soil?
7. What is a "fossil"?
8. Explain the expression "the story of the rocks."
9. Which rocks usually yield more ancient records, those near the surface or those deeper down? Why?

10. What is the reason that the most ancient rocks are not always found deepest in the earth?
11. Mention one change in the earth resulting from each of the following agencies: water, heat, animals, plants, earthquakes, contractions of the earth's crust, glaciers.
12. How are coral reefs and islands formed?
13. What is the evidence that the New Jersey coast line was once (*a*) farther inland, (*b*) farther seaward?
14. What forces (name several) which operated in past time are now at work changing the earth?

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CHAPTER V

THE HISTORY OF MANKIND

Problems:

1. What are the ways in which man has progressed from savagery to civilization?
2. How are living things named and classified?
3. In what ways has man made use of plants and animals?
4. In what ways has man's presence affected plants and animals?

Foreword. In the preceding chapter we discussed the changes that are taking place in our environment. Let us now consider the ways in which man has become the dominant type of organism. No argument is necessary to convince us that we are the dominant organism on the earth. Other types sometimes challenge our claims to supremacy. Man has been rather successful, however, in competition with other forms of life.

When we consider the relationship of man to the world of today, it appears that he has largely succeeded in the struggle for existence. He also is making use of many species of plants and animals. Some insects, some weeds, a few of the larger animals, and some microbes still threaten the security of man, or compete with him for the food supply. Over most other types of life man has gained more or less control.

The things man has made — the tools, the houses, the engines, and the ships — these possessions give him a sense of power over nature and a feeling of superiority over other organisms. But records of history tell us that he did not always possess such power. For instance, consider the telephone as a means of communicating over long distances. It was preceded by the telegraph. This was preceded by personal messenger or by flashing signals with mirrors. This again was preceded by the use of fire or smoke signals, and so on until communication was limited to distances within range of the eye or ear. In a similar way, most if not all modern appliances were unknown to primitive man.

KNOWLEDGE OF PRIMITIVE MAN COMES FROM THE STUDY OF FOSSILS AND RELICS

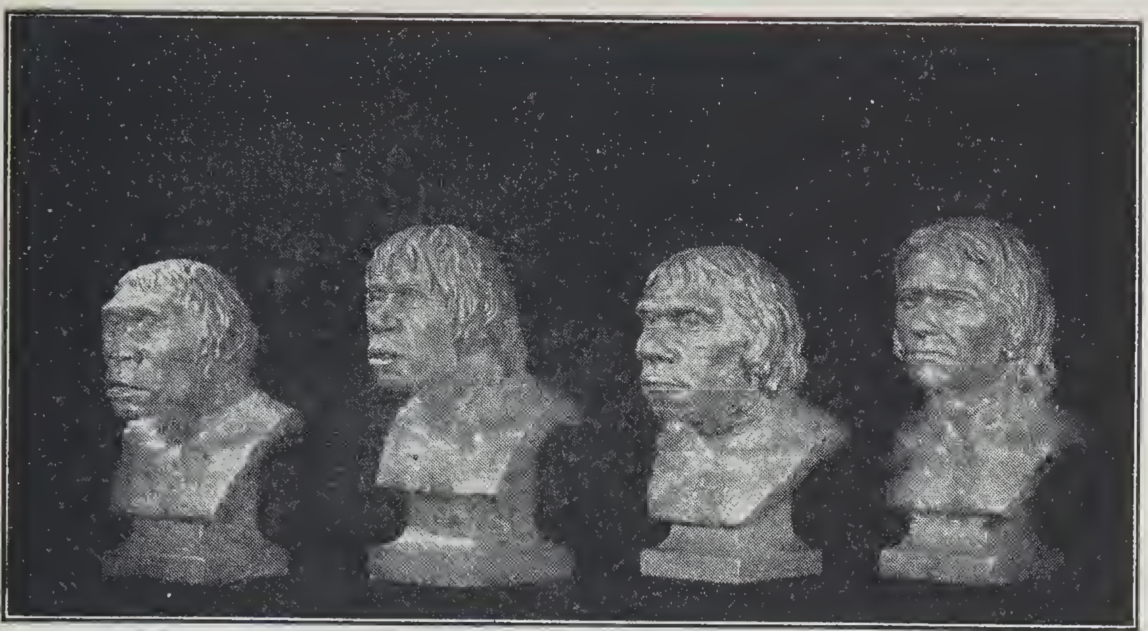
Suppose you yourself were to go now into some jungle of South America or Africa, without tools, or guns, or knives, or food, or clothing, or matches, or horses, or wagons, or shelter of any kind. How well do you think you would succeed in maintaining your life? What would you do first? How would you protect yourself against cutting your bare feet on the rocks? What would you eat? If you wanted meat how would you capture or kill an animal? Where would you sleep at night and how would you keep warm if it happened to be cold?

Your ancestors thousands of years ago had to face just such problems. They also had to solve these problems and overcome these obstacles to life — otherwise you would not be here. We of the present generation are the heirs of past generations in more ways than we may realize.

Fossils and relics of man. Our knowledge of prehistoric man is derived from evidence such as the discovery of human bones, carvings on rocks or ivory, and from implements or relics of various kinds which have been unearthed or found in caves. Only the most thoroughly trained geologists are competent to decide the probable ages of fossils.

There have been found in various parts of the world, bones of several different types that are alleged to be those of prehistoric man. Several of these are referred to so commonly as to merit mention. They are called Java man, Peking man, Heidelberg man, Neanderthal man, Piltdown man, and Cro-Magnon man.

Java man. The remains of Java man (Pithecanthropus) represent only parts of a skeleton. Evidently this type lived at a remote period. It is by no means certain that Java man represents a direct ancestor of modern man. The deposits in which the fossil parts were found probably date back to the early part of the Pleistocene or glacial period.



American Museum of Natural History, New York.

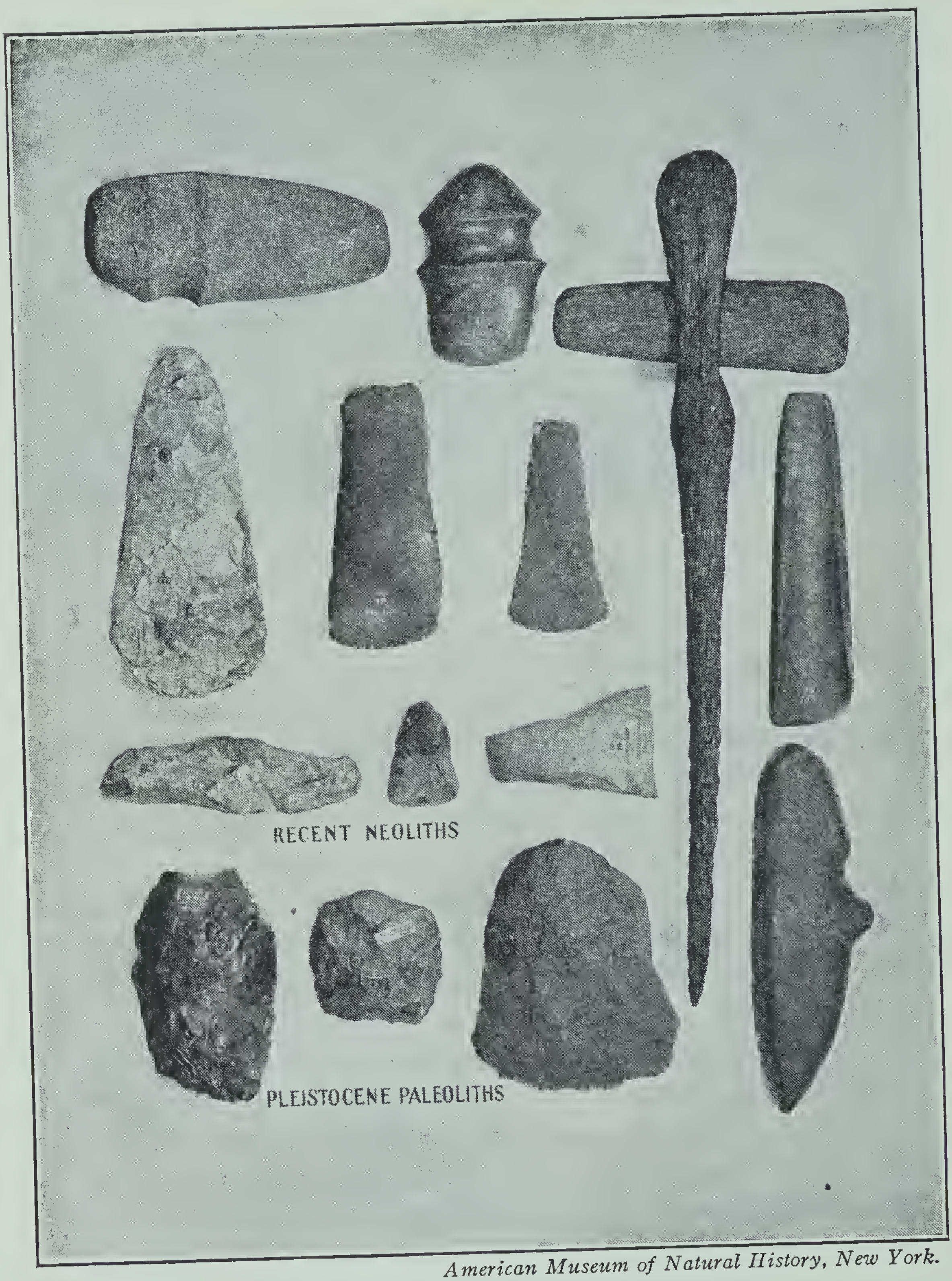
FIGURE 46. Prehistoric types of men. From left to right: Java man (Pithecanthropus), Piltdown man, Neanderthal man, and Cro-Magnon man. Restorations by Professor J. H. McGregor.

Peking man. Recent discoveries indicate that Peking man was living farther to the north and east at this same early period. It is thought that Peking man may have lived on somewhat beyond the time of Java man.

Heidelberg man. Probably Heidelberg man lived in the Eurasian region at a later date than either of the preceding types. Our knowledge of Heidelberg man is based upon a fossil portion of a jaw found in glacial deposits of Germany.

Piltdown man. This type is known from an incomplete skull that was found in England. Authorities do not agree as to its probable age. One estimate places Piltdown man in the third inter-glacial stage, perhaps about 150,000 years ago.

Neanderthal man. Neanderthal man is represented by more numerous fossil remains. About thirty fossil evidences of this type have been found in various parts of Eurasia. Some of the fossils represent more or less complete skeletons. Perhaps Neanderthal man descended from the more primitive Heidelberg man. Neanderthal man probably lived during or before the fourth glacial invasion — from about 30,000 to 100,000 years ago.



American Museum of Natural History, New York.

FIGURE 47. Implements used by primitive human races; the more recent types are to be seen in the upper part of the group.

Cro-Magnon man. The Cro-Magnon type, as reconstructed from five skeletons found in a cave in France, was very much like modern man in size, skull capacity, and shape of the face. Cro-Magnon man appears to have lived after the time of Neanderthal man, probably after the last invasion of the ice, or about 70,000 years ago. The end of the glacial period marks the end of the "old stone age" and the beginning of the "new stone age."

In addition, fossil records indicate the existence of at least two other races of man that have long ago become extinct. These are the so-called Rhodesian man, and Kanam man. In recent years excavations have been made in various parts of North America in more or less successful attempts to find human fossils and relics. We should like to know much more about the first Americans.

Efforts have been made to establish the comparative ages of these different fossil men upon the basis of the ages of deposits in which they are found. It is sufficient for our purposes to say that all of them are fairly recent, as geological time is measured. The relationships that these types may have had to each other, or to modern man, present a difficult problem.

The absence of human fossils in any geological period cannot be taken as positive evidence that man did not exist at the time. Human remains ordinarily would not be deposited in the sediments of the ocean bottom to be preserved, as many other forms of life have been. Most of them would be left on the land, and when in or near the surface would be more likely to decay than to become fossils.

The modern "races of mankind" are varieties which have resulted from variation and adaptation to environment. Formerly several types were recognized, such as the Mongolian (yellow skin and straight hair), the Caucasian (white skin and straight or wavy hair), the Negro (black skin and kinky hair), the Malay (brown skin and straight hair), and the American Indian (red or coppery skin and straight hair). Probably no race is distinct, because it is likely that modern types had a common origin, and there has been considerable mingling of races.

MAN'S PROGRESS HAS BEEN RELATED TO CONTROL OF ENVIRONMENT

Life of primitive man. From the study of relics, we can form a fairly good picture of the kind of life prehistoric man lived. Such relics include flint arrowheads, stone knives, and other implements, carvings on rocks, and metal or bone ornaments. All of these are evidences that whatever may have been primitive man's face or form, his mode of life was very simple. Such evidences of human activities have been found in geological formations that belong to the glacial period. The dates for the beginning and ending of this period are variously estimated. It seems probable, however, that a very primitive type of human life existed 400,000 years ago. Most relics seem to be of far more recent origin.

As nearly as we can reconstruct them in our imagination, human beings were at first unclothed, without tools, houses, fires, or even speech. The first tools probably were sticks and stones which were found ready for use. Soon the shaping of implements for desired uses was seen to be an advantage. Far back in the glacial period stone implements, fashioned by hand, were made by man. Later he learned to make fire, perhaps by using sparks from flint and iron ores, or perhaps by rubbing pieces of wood together.

Hunting and fishing stage. The problems of food, shelter, and protection against the other animals were met very simply. Berries, bark, roots, and nuts eaten raw, probably were his chief foods, together with small animals killed by spears, arrows, or clubs. Shelter was provided by caves, and later by rude tents or huts made in part from the skins of animals. Pictures carved on rocks by primitive man exhibit huts similar to those used by the American Indians at the time of the discovery of this continent. The chief activities must have been gathering vegetable foods and capturing wild animals, or avoiding being captured by them. This early stage in the life of primitive man is sometimes called the hunting and fishing stage.

Some writers call this period of man's development the stone age because of the prevalence of stone implements. These historians have divided the period of man's early development into (1) the Old Stone Age (Paleolithic Period), (2) the New Stone Age (Neolithic Period), (3) the Bronze Age, (4) the Copper Age, and (5) the Iron Age. These terms refer to man's progress in the use of materials for tools. In the beginning, man used sticks and rocks as he found them. Soon he crudely fashioned stone hatchets. As his skill improved, his tools likewise improved. Hence, the use of copper and iron represent increasing knowledge and skill in extracting metals from the earth, and in adapting them to human wants.

It ought to be understood, however, that by the end of the glacial period (Pleistocene) men were living in various parts of the world. Culture probably was more highly developed by some groups than by others. While tribes in what is now Europe, for example, were making stone implements, other tribes elsewhere may still have been using clubs and may not have known how to make many simple tools. At the same time, or somewhat later, other tribes living in other regions, may have advanced beyond this stage. They may have been using bronze or iron implements, or have progressed into a stage of culture in which animals were herded.

Today, uncivilized races exist in Africa and some of the South Sea Islands where a "state of savagery" is still the best description of their lives. We should not think, then, that mankind all over the earth was at any one time in a stone age, or in any other age. The truth appears to be that all races of mankind started, at one time or another, in a state of savagery. By more or less gradual development some tribes passed from a period of using stone implements to periods when they used more and more complicated devices for obtaining the necessities of life.

The superiority of primitive man over other animals is indicated in no better way than by the tools which he fashioned. When bronze, iron, and other metals became known to man, he used these materials for his tools and found them adaptable to his hands. Thus implements and practical or ornamental devices in bronze and iron, found by excavations into various deposits of soil and gravel, give rise to the expressions the Bronze

Age and the Iron Age. At the time which we have called the beginning of the historical period, the Egyptians were using copper and bronze implements.

Herding. It may be said that mankind's development progressed from the hunting and fishing stage to the herdsman stage. It appears that the domestication of animals — sheep, goats, horses, camels, and others — was an easy and natural consequence of the need for food and skins. Keeping such animals in herds, raising them, and killing them when the need arose, proved to be easier than hunting them and trusting to chance for daily meals. At the same time man in various places developed language, both speech and writing. Families grew into tribes with ancestral chiefs. More permanent places of abode, such as stone houses, made their appearance. Crude art and music occupied men here and there, and beginnings of what we call culture came into existence.

Agriculture. Wherever men domesticated animals, some attempts to grow food for them naturally were made. Soon certain peoples settled down in more or less permanent locations where food crops were cultivated. Such grains as wheat, barley, and millet were grown for food. Pottery, basket-weaving, textiles, crude plows, and wheel carts made their appearance. Community life grew rapidly until villages, or even cities of several thousand individuals, could be found. Western Asia, Egypt, Europe, and the entire basin of the Mediterranean are centers where we find evidences that such a type of civilization was developed at various times in the past.

Trading. Gradually men began to exchange goods with one another. There were tribes or groups of people who continued to hunt game. Others preferred to roam through the country with their flocks, seeking new pastures as the old ones became barren. Some of the people who lived in cities came to employ their time making tools and clothing. These articles they exchanged with farmers for grain or with herdsmen for meat or hides. Thus trade grew as a natural, intelligent manner of securing the necessities of life from those who were best able to supply them.

The advantages of this division of labor soon became apparent. New occupations appeared. Caravan drivers, storekeepers, sailors, traders in skins, ivory, silks, precious stones, and implements of many kinds became necessary to supply rapidly increasing needs of people in widely separated localities. Tribes became nations, and nations developed their own civilizations.

The beginnings of historical records. Early Egyptian records of one sort or another date from about 4000 B.C. Babylonian records probably go back to approximately 3000 B.C. In other parts of the world history dates from different times. The records of India and China do not give us knowledge of facts earlier than perhaps the tenth century B.C.

Therefore, we cannot say that history began at any one time in the social development of all human races. Further, we must conclude that most or all races passed through successive stages of savagery, herding, agriculture, trading, and development of handicrafts. Each race or tribe began to keep written records when it arrived at a social state that made such records necessary or desirable. Before producing written records a race must have spent hundreds or thousands of years in a slow social development.

Even in historical time we can see that the rate of progress has not been the same for all races. At the beginning of the Christian Era the Greeks and Romans had developed a relatively high state of culture in art, literature, politics, and philosophy. Yet at the same time the Gallic tribes — the Vandals and the Huns — had advanced little beyond a state of savagery with respect to these features of civilization. Not until ten centuries later did the peoples of Europe as a whole reach a state of civilization comparable to that in the city-states of Greece and Rome.

The medieval period. The medieval period began after the fall of the Roman Empire. During this time there were few advances in civilization. Such science as existed was in the hands of the monks. They revered the teachings of Aristotle as to the nature of the universe and on the subject of life. Galen, an anatomist who lived during the days of the Roman Empire, also was regarded as an infallible authority. Such slavish belief in the statements of earlier students tended to prevent the discovery of new scientific facts. During this period, the monks cultivated crops, raised domestic fowls, and exerted an influence in maintaining the level of culture which man had attained.

The feudal system reigned during medieval times. Cities grew. Agriculture was developed by the wealthy gentry and the feudal barons. Hand trades formed guilds or associations. Markets within cities flourished, but trade between cities or countries was a dangerous venture because there were so many robbers. Later, a brisk trade grew up among Mediterranean peoples, and was flourishing in the time of Columbus.

The entire period from the fall of Rome until the exploration of the new world, was marked by a lack of achievement in knowledge of the world and control of its forces. In the days of Rome, tuberculosis, malaria, bubonic plague, and other diseases had been very common. During medieval times, conditions of public health were worse, if anything, than they had been. Plagues were supposed to be visitations of Providence, as a punishment for sins. The appearance of comets was thought to warn against the coming of such plagues. Various people were tortured or burned at the stake because it was suspected that they were responsible for the diseases in question. In the absence of real knowledge of the scientific facts, people turned to superstitions in an effort to explain the mysteries of life.

This faith in superstitions should not surprise us. In the early days of New England it was not uncommon to accuse people of being witches, and to punish them accordingly. Even today we find many superstitions surviving. Some people wear charms in a foolish belief that they will ward off disease. Or they fear bad luck in the future if a black cat crosses their path or if they accidentally break a mirror.

The use of domesticated animals and cultivated plants was continued and extended during the medieval period. Horses were used for purposes of war, in messenger service, and in farm work. Oxen were used for plowing and for drawing carts. Dogs, hens, cats, cows, sheep, and other animals were or became man's

FIGURE 48. A dromedary, or camel — a domesticated animal.

companions and servants. Grapes, barley, peas, beans, and other vegetables were cultivated. The preparation and use of flour, wine, dyes, glass, cloth, leather, and iron was extended. Many contrivances for lessening human labor had long since been devised. Hand-craftsmanship in the arts of preparing many of these things, by the opening of the fifteenth century, was equal or superior to that of the twentieth century. But the machine age was far in the future.

Rise and fall of cultures. While our discussion has directed attention largely to Europe, it should not be understood that man was limited to that area. In China, India, Africa, and America, at the same time, branches of the human race were developing civilizations of their own. These civilizations were quite independent, however. Until the period of exploration and trade, they were unknown, for the most part, to the peoples of Europe.

Moreover, some of these civilizations, which may have been as advanced or more advanced than that of Europe, have come to an end. Some, such as the Mound Builders in the Mississippi

Valley, have disappeared. The Mayas of Mexico, Central, and South America, reached a state of advanced culture. Their activities included temple-building, agriculture, domestication of animals, political organization, writing, and many arts. This civilization was also brought to an end, and the descendants reverted to savagery. The causes of the fall of civilizations are various. War, pestilence, famine, and moral or physical degeneration no doubt played a part at various times and in various places.

Modern civilization. In your history, dates, no doubt, will be set for what are called ancient, medieval, and modern history. Our interest lies rather in the successive steps by which mankind, through increasing control over himself and over plants, animals, and the forces of the world, has reached his present position.

MAN IS LEARNING TO CONTROL HIS ENVIRONMENT

We have now seen that mankind became successively herdsman, farmer, handicraftsman, and trader. In each successive stage the essential activities of the preceding one were continued. No city life could exist except for the production of food by someone. This means that cattle-raising and agriculture in general are likely to remain fundamental in all present and future civilizations. When handicrafts and trade came to occupy the attention of an increasing number of men in all progressive nations, agriculture became no less important. On the contrary, it was constantly receiving thoughtful attention from many people. When machinery began to be used in the manufacture of commodities, some hand work continued to be necessary. There was an increasing demand for biological raw materials such as cotton, hemp, silk, lumber, cereals, leather, and extractives. With this demand came the problem of improving the quality and increasing the number of useful forms of life.

The scientific age. The period of modern civilization is often called the scientific age. This term suggests not only the abandonment of haphazard dependence upon the forces and materials of the world, but also a deliberate effort to study them and make use of them in an orderly fashion. Emphasis by writers of the industrial revolution and of the scientific modern period is placed upon machines. Even greater attention should be directed, however, to biology as effecting these changes in the world, or as being affected by them.

One of the first steps in gaining an understanding of nature was to study and classify plants and animals. Useful plants had to be recognized and distinguished from useless or harmful ones. Certain species of animals could be catalogued as harmful, useful, or neutral types. No doubt a good deal of such information was passed from father to son among primitive men. Gradually, a fund of knowledge about natural objects was built up. Aristotle, among others, attempted a classification of organisms that were known to him. The first written classifications were, of course, rather crude affairs. As time went on a system was gradually perfected. This study of classification is called taxonomy.

Homology. Biologists classify organisms upon the basis of their likeness in structure. Only real or basic similarities are considered. Such similarities are called homologies. Thus the arm of man is homologous with the foreleg of a horse because, generally speaking, the bones, nerves, and muscles of the one correspond to similar structures in the other. Furthermore, both structures have the same general origin in the process of early development.

On the other hand, the wing of a grasshopper or the limb of a tree would not be homologous with the arm of man and the fore limb of a horse. The wing of a grasshopper does not represent a fore limb, but is developed from the external skeleton. The limb of a tree, although called a "limb," has no structural relationship to the limb of an animal. Nor would we classify a rabbit, a frog, and a grasshopper in one small group because all of them can jump. Jumping represents a similarity of activity rather than a similarity of structure.

In scientific classification, a bat and a bird are placed in one large group called vertebrates, because, among other things, both develop backbones. Birds, however, have feathers, beaks, and other structures which cause us to call them one kind of

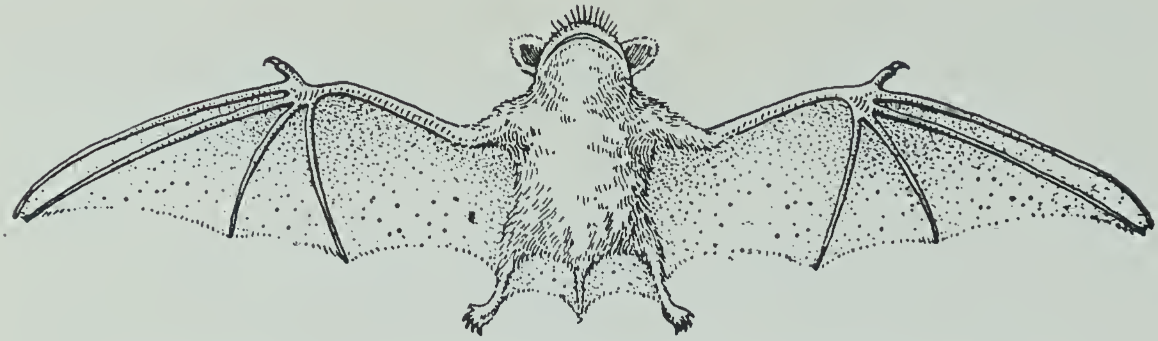


FIGURE 49. A bat, illustrating the type of wing development.

vertebrate — the birds. Bats have hair, teeth, milk glands, and other structures which mark them as members of another group of vertebrates — the mammals. A grasshopper is not placed in the vertebrate group because it does not develop such a structure as a backbone. Since it lacks a backbone, a grasshopper must be classified as an invertebrate. Thus we see that organisms placed in the same classification group must have certain fundamental structures in common.

Classification groups. The main classification groups used in modern biology, in order, from the largest to the smallest, are as follows (the plurals are given in parentheses):

Kingdom (kingdoms)
Phylum (phyla)
Class (classes)
Order (orders)
Family (families)
Genus (genera)
Species (species)
Subspecies (subspecies)

In the following table we may observe the application of this system to a number of animals, most of which have been studied in the preceding chapters.

Sometimes, as you may note in the table, it is not necessary to use all of the divisions. Moreover, in your future study, you may discover that authorities differ in their judgment about the classification of an organism. This difference in opinion is partly due to the fact that the system has been developed in

TABLE I. SOME CLASSIFICATION GROUPS

	AN AMŒBA	AN EARTHWORM	A GRASSHOPPER	LEOPARD FROG	CAT
Kingdom	Animal	Animal	Animal	Animal	Animal
Phylum	Protozoa	Annelida	Arthropoda	Chordata	Chordata
Class	Sarcodina	Chætopoda	Insecta	Amphibia	Mammalia
Order	Lobosa	Macrodrili	Orthoptera	Salientia	Carnivora
Family			Acridiidæ	Ranidæ	Felidæ
Genus	Amœba	Lumbricus	Melanoplus	Rana	Felis
Species	proteus	terrestris		pipiens	domesticus

various countries and by various scientists. In part, however, it is due to new discoveries which make necessary from time to time a regrouping of some species.

The scientific name. The scientific name of a species is a part of the classification system. It has arisen out of the necessity for names which will be used all over the world. The use of local names, which vary in different places, would be certain to cause confusion in scientific work. A Swedish biologist named Linnæus (1707–1778) originated the so-called binomial system of naming. Under this system a scientific name consists of two parts. The first part is the name of the genus. The second part is the name of the species. For example, man belongs to the genus Homo and the species sapiens. Therefore, the scientific name of man becomes Homo sapiens. Note that the generic name is placed first and is capitalized; the specific name ordinarily is not capitalized.

Or, to use another example, the paper birch tree is called Betula papyrifera Marshall. This indicates that it is of the genus Betula, the species papyrifera (paper-making), and was named by Marshall. The addition of the name of the person who first described the species is a courtesy, and often an aid in tracing the origin of names.

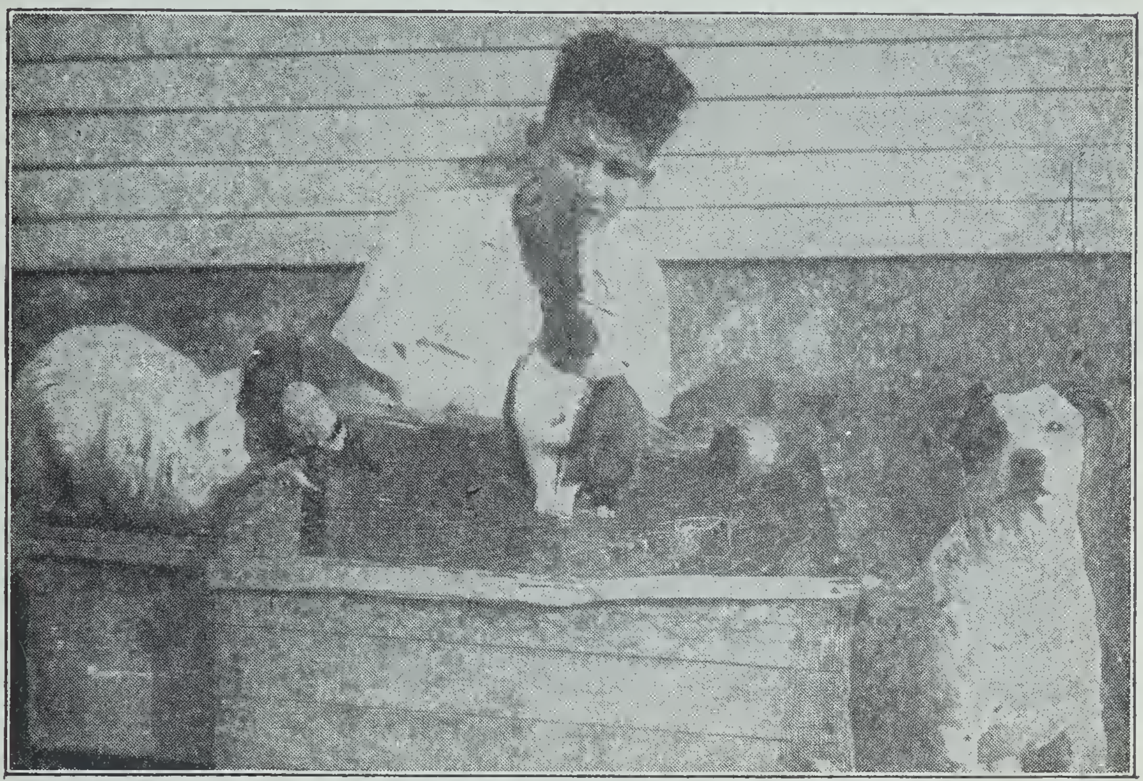
Subspecies. In the cases of some species, a third term has been added to the scientific name to designate the subspecies. The subspecies is a division of a species — a certain variety of that species. For example, the common meadow lark of the East is called Sturnella magna magna. A Western variety of the same species is called Sturnella magna neglecta. It will be noted that the third name in each case is the name of the subspecies.

In the preceding discussion you have learned that species means the kind of organism. Genus, of course, refers to the next larger grouping, which may include several species showing close relationship. A family would be composed of several related genera, an order of several related families, and so on.

The advantage in having a uniform system of classification should be obvious. When a biologist makes a discovery of some new fact, other biologists are not left in doubt as to just what species are involved.

Improvement of the environment. There used to be a saying that man could not improve nature. It is no longer wise or even sensible to say this. Man has improved nature and is improving natural surroundings in a number of ways. In providing for his own needs, man has selected from the great variety of living things those which he has desired. Plants which he has selected and cultivated have been protected from enemies, planted in rich soil, and cared for until by selection and improved environment, their size, vigor, and other natural qualities have been developed enormously.

Cultivated plants. From one insignificant kind of weed, cabbages, turnips, kohl-rabi, cauliflower, and Brussels sprouts have been derived. Corn was in cultivation by the Indians when America was discovered. It is believed to have descended from one or more wild Mexican grasses. From such sources man has developed sweet corn in colors of blue, white, or yellow, corn for starch, corn for oil, corn for cattle feed, popcorn, and many other varieties used for special purposes. Wheat, which is the world's most valuable cereal, has been improved within the last twenty-five years so that certain varieties now yield eighty bushels per acre. This is in contrast to the ten or twelve bushels, which was the former average yield. "Kanred" and "marquis" are two notable varieties of wheat produced by scientific breeding. Luther Burbank became famous for his work in improving cultivated plants by experimentation and selection.



Acme.

FIGURE 50. Domesticated animals as pets. Can you name them?

Domesticated animals. Animals which could be used by man have been domesticated and thus removed from much of the competition with wild animals. Since very ancient times man has raised horses, pigs, sheep, cattle, goats, camels, pigeons, and chickens. Some of these, under man's protection, have multiplied until they far outnumber the wild species with which they once competed. In some of these cases the wild ancestors are not even definitely known, so old are the domestications.

Selection, guided by man, has developed numerous varieties of cattle, pigs, sheep, and poultry. Some of these new varieties are quite different from their wild ancestors, but are well adapted to certain of man's purposes. For instance, the jungle fowl does not resemble its descendant, the white leghorn, very closely. But good strains of white leghorn hens are desirable from the human standpoint.

Destruction of undesirable species. Of course it follows that plants which are poisonous or which have no known uses are destroyed by man. Weeds interfere with the growth of food crops and man tries to remove them. He burns over great areas to kill these weeds. He plows them under or cuts them down as fast as they appear in his crop areas. Certain types of animals have been destroyed in large numbers because they were carriers of disease, or because they attacked man's crops or domesticated animals.

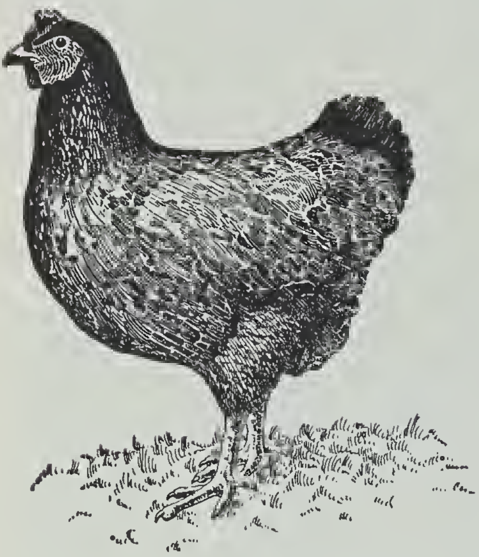


FIGURE 51. A variety of the domesticated chicken.

Competitors and natural enemies of man. In our modern world we find that man has by no means conquered his natural enemies and competitors. In most places he no longer fears the attacks of large, natural enemies. However, tigers still kill human beings in Asia. Venomous snakes are a serious problem in parts of Asia, Africa, Central America, and South America. Many species of insects destroy crop plants and some of them carry diseases. Great advances have been made in the control of plagues and microbes in general, but much work remains to be done. Parasites and natural enemies still attack our domesticated animals. Weeds are all too common despite modern methods of cultivation. Small animals such as rats and mice destroy enormous quantities of food materials and other goods.

Other changes in the environment. Man's rise to dominance has greatly affected the lives of other organisms. Draining of swamps destroys semi-aquatic forms of life, or forces them to migrate. They are replaced by organisms that live successfully upon the land. Irrigation of desert areas may result in the luxuriant growth of vegetation. Streams have been polluted as a result of man's activities. Forests have been destroyed, often with unfortunate results. Some species have become extinct.

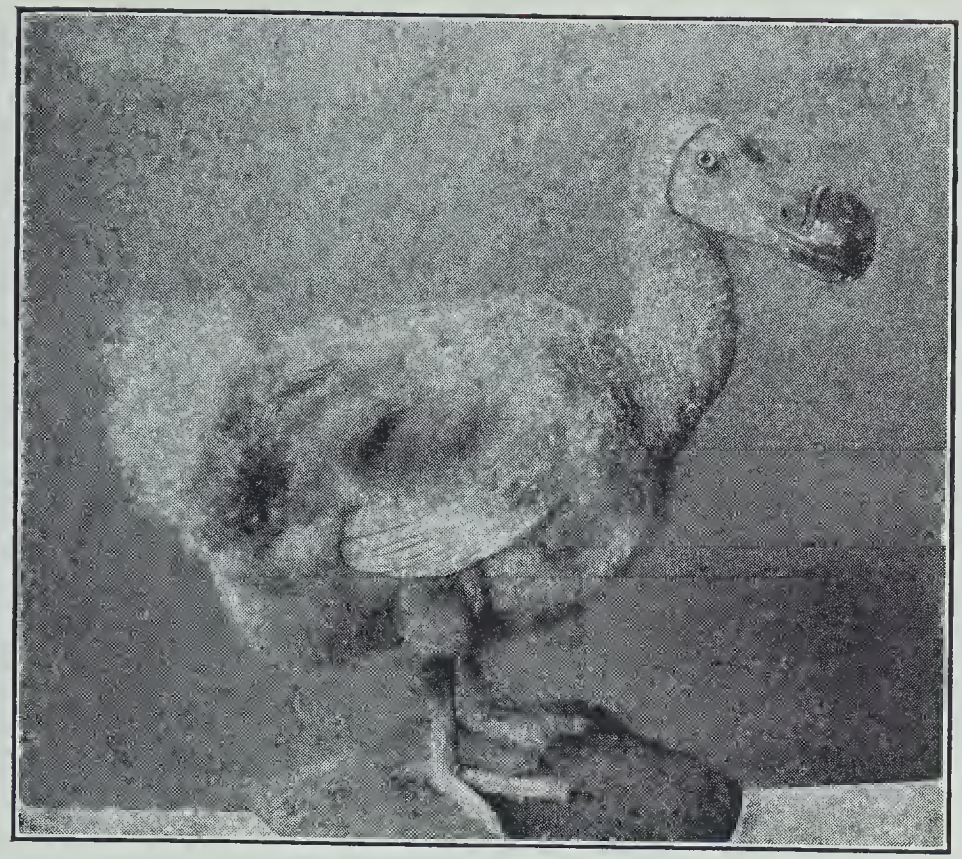
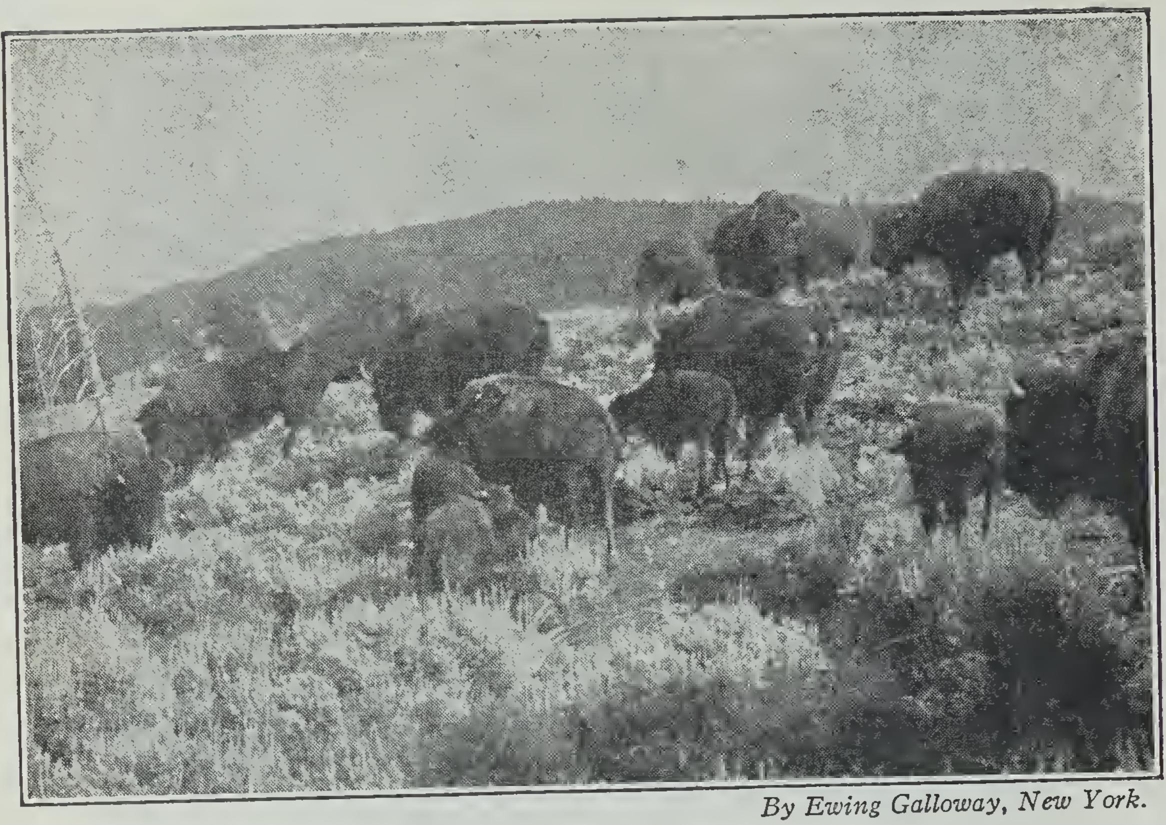


FIGURE 52. A restoration of the extinct Dodo. (Courtesy of Professor H. R. Dill.)

at least in part, because of man's destructiveness. Man has introduced many species to new areas. Some introductions have been deliberate; others have been accidental. Some have been fortunate; others have had very unfortunate results.

Progress in civilization. Man's progress from savagery to civilization has been gradual. Our earliest records of man are fossil remains found in various parts of the world. These fossils are of comparatively recent age as geological time is measured. The progress of man in civilization has not been uniform for all tribes in all parts of the world.

Today we live in what is sometimes called the scientific age. Man has made great progress in gaining control over his environment. As far as the biological environment is concerned, man has made some notable advances. He has classified plants and animals. Certain species have been cultivated and domesticated. Some natural enemies and competitors of man have been brought under control.



By Ewing Galloway, New York.

FIGURE 53. A herd of bison; animals which formerly were very common, but which became almost extinct. Under protection, bison have increased in number in recent years.

Man's presence has interfered with the lives of plants and animals in many localities. Species have become extinct. Others have been introduced to new regions. The balance between species in many regions has been disturbed. Man has learned that such disturbance may have far-reaching effects. The lives of all organisms are interdependent. The welfare of man is related to the presence or absence of other organisms.

In some cases in which man has disturbed the balance among organisms with unfortunate effects, he has been able to correct or minimize the undesirable results of his acts. Eventually, it seems possible that we shall understand the interrelationships of organisms so well that the majority of organisms may be used to advantage, brought under control, or ignored if they have little effect upon human welfare. In any event, it is evident that a knowledge of plants and animals is of vital importance to human progress.

FIGURE 54. A scientist at work. What sort of exploration is being made here? What is the instrument which is being used?

Science and man's success. We see then that much of man's success has been due to his ability to learn the laws and principles which govern affairs in this world. Gradually there has been gathered a vast amount of classified, organized knowledge.

This knowledge of facts and principles is known as science. So vast is the amount of this knowledge and so numerous are the problems to be solved that science has been divided into branches for more successful study.

Among the important branches of science are biology, chemistry, physics, and geology. Biology is the study of living things. Chemistry is the study of changes in the composition of substances. Physics is the study of changes in matter and energy. Geology is the study of changes in the earth — especially rocks. Many of these branches of science are further subdivided. Biology, for example, has branches such as physiology, the study of function; anatomy, the study of structure; botany, the study of plants; zoology the study of animals.

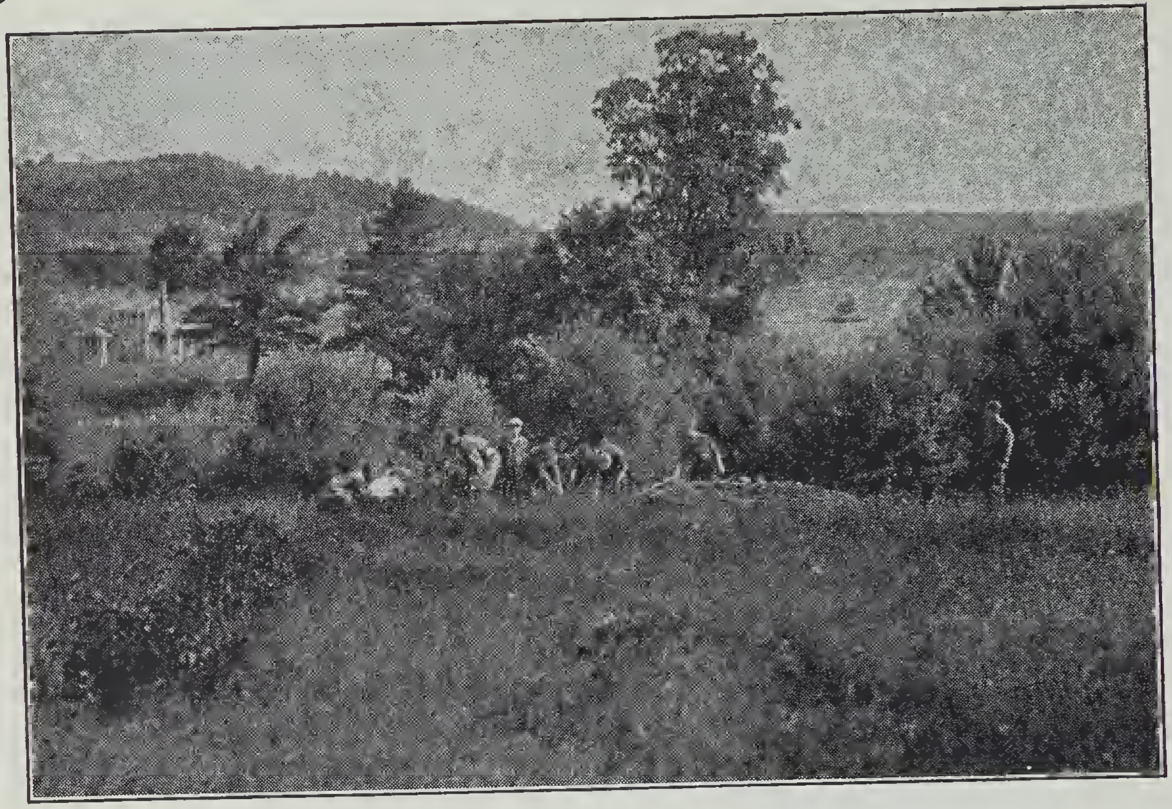


FIGURE 55. Uprooting currant and gooseberry bushes which act as hosts of the white pine blister rust. (Courtesy of the New York State Conservation Department.)

Scientific methods. Science, as we understand it today, is to be looked upon as a kind of exploration for the purpose of advancing knowledge, rather than the study of knowledge previously obtained. The methods by which scientists obtain facts and study the principles at work in the world have come to be known as "scientific methods." Perhaps there is no one scientific method, but it is possible to list some of the things that scientists consider important. It is very desirable that students engaged in the study of science should begin to learn to use these procedures.

No doubt students of biology have already become acquainted with some of these methods in their introductory science courses. Biology gives rich opportunity for learning more of them and for practice in their use. As we progress in the study of biology, the work of many scientists will be referred to. Their methods should serve as patterns for our own practices. In our demonstrations, experiments, and other activities, it is to be expected that scientific methods will be used. For while knowledge of biological facts is important, much more important is the learning of scientific methods in our daily work and thinking. Biology, then, may become a means for scientific training rather than merely a "subject."

Some methods of a scientist:

1. A scientist bases his beliefs upon facts.
2. Facts are obtained by observation.
3. Experiments are methods of bringing about conditions so that happenings and facts can be observed.
4. Facts should be recorded at the time of the observation.
5. Experiments should be planned before they are started.
6. A carefully stated purpose should be in mind for every experiment.
7. A good scientist is careful and orderly in his work.
8. A scientist has a "check" or control [1] for an experiment — in some cases a number of controls.
9. It is best to change only one condition at a time when experimenting. This is known as the principle of the "single variable."
10. The outcomes of an experiment should not be accepted as true unless verified by repetition — often several repetitions.
11. Conclusions or generalizations should not be made from one fact or few facts.
12. A scientist considers his results from one experiment as temporary conclusions and not final. Usually one experiment leads to a question which in turn leads to another experiment, or further investigation.

Scientific attitudes. Scientists are sometimes said to have certain habits of thinking which are called "scientific attitudes." Among these are the possession, in some degree, of such qualities as:

1. Curiosity about how and why things happen.

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[1] A "control" refers to some means of making comparisons between the facts resulting from the changed conditions and the facts without the changed conditions.

2. Respect for truth.
3. A critical attitude toward their own work and the work of others.
4. The habit of holding back decisions while looking for facts.
5. The habit of forming conclusions upon the basis of *evidence* — not upon the basis of *opinion.*
6. Readiness to change beliefs when confronted with facts which disprove these beliefs.
7. An attempt to remain free from bias or prejudice.
8. Recognition of the fact that effects are due to causes.

SUGGESTED ACTIVITIES

Scientific methods

A scientist looks for relationships of cause and effect among facts, and forms conclusions based upon these relationships.

1. Bring to the class any relics of ancient cultures that can be obtained. Study how they were made, their uses, and the modern devices that have replaced them.
2. Visit a museum. Examine fossils, reconstructed types of man, and relics of ancient cultures.
3. After consulting the reading references at the end of this chapter, make models, charts, or drawings of articles concerned with man's progress in civilization.
4. After consulting the reading references at the end of this chapter, explain by drawings and discussion the idea suggested by "stone age" in man's cultural development.
5. Demonstrate the making of fire with flint and steel, or bow and drill.
6. After consulting the reading references at the end of this chapter, select some occupation of man, and write an historical report of its development. Illustrate with drawings or pictures of implements used in the various periods.
7. Make a collection of pictures from magazines which illustrate the stages in man's progress. Mount these in a form suitable for display on the walls of the classroom.
8. Look up the classification of the dog and any species of frog in some zoology textbook. Using a systematic botany, do the same in the cases of a dandelion and a rose. Prepare a summary, giving the phylum, class, order, family, and genus for each type.

9. Select any one of the animal or plant types listed below (any variety). Investigate its origin as a domesticated type, its uses to man, and its importance to man throughout history. Prepare a report, illustrated if possible. Corn, wheat, cabbage, cotton, potato, tobacco, horse, hen, cow, sheep, pig.

SUMMARY OF PRINCIPLES

1. Man is a dominant type of organism in the modern world.
2. Prehistoric human fossils and relics have been found in various parts of the world.
3. Among the more important prehistoric human types are Java man, Peking man, Heidelberg man, Piltdown man, Neanderthal man, and Cro-Magnon man.
4. The evidence indicates that man has been on the earth for a great many years, although this time interval is not long as geological time is measured.
5. The chief stages in mankind's development are (*a*) Hunting and Fishing, (*b*) Herding, (*c*) Agricultural, (*d*) Handicraft and Trade, (*e*) Industrial, and (*f*) Scientific.
6. The progress of man has been at different rates in different places but has been marked by increasing control of the environment.
7. Man's activities have greatly affected the lives of plants and animals all over the world.
8. Use of the scientific method has resulted in knowledge of facts and principles concerning the world about us.

GUIDE QUESTIONS

1. In what places are fossils of prehistoric man found?
2. Which are more numerous, fossils of man or fossils of other organisms? Why?
3. According to the fossil evidence, when did man appear on the earth?
4. Discuss the successive stages in man's progress before the scientific age.
5. What were the advantages to man in herding animals?
6. What changes in social life grew out of the agricultural stage of development?
7. What is the source of the earliest historical records?
8. Did all mankind develop civilization at the same rate? What is the evidence?
9. State some facts about the condition of civilization during medieval times.

10. Why have plants and animals been classified?
11. What is the binomial system?
12. Name ten plants that have been cultivated.
13. Name ten animals which have been domesticated.
14. Has man brought all other organisms under control?
15. What are some of the competitors and natural enemies of man?
16. In what ways has man disturbed the "balance" in nature?
17. Discuss some procedures which are related to use of the scientific method.

BOOKS TO READ

Andrews, R. C. *On the Trail of Ancient Man.*
Cleland, H. F. *Our Prehistoric Ancestors.*
Keith, Sir Arthur. *The Antiquity of Man.*
Kroeber, A. L. *Anthropology.*
Lull, R. S. *Ancient Man.*
Mather, K. F. *Sons of the Earth.*
Sears, P. B. *Life and Environment.*

UNIT II

PROTOPLASM, THE CELL, AND THE ORGANISM

IN THE preceding unit we have learned something about the environment of living things. We find that environments change continually, and that plants and animals must adjust their behavior to certain of these changes.

Perhaps you have noticed that living things resemble one another in certain ways, even though there are many different kinds of living things. All living things are more or less sensitive to changes in their environments. They require food or food materials if they are to grow. They use oxygen to oxidize certain substances, thus releasing the energy that these substances contain. Waste products of bodily activities must be removed from the organisms. We have noted that many animals and some plants are able to move from place to place, and that most living things can contract certain parts of their bodies, even though this may not enable them to move about. Finally, all living things have some means of producing new individuals of their own kind.

These facts indicate that there is some underlying similarity of function among organisms. One of the questions we must answer is whether or not there is some basis for this similarity of function. Is there a living substance that is common to all organisms? What are the units or smallest parts of a large or complex body?

When we have answered these questions we shall find that certain functions and structures are common to all plants and animals. It will remain to discover to what extent organisms differ from one another. How does the plant differ from the animal? What is the distinction between a simple plant or animal and a complex plant or animal? What happens when the body of an organism becomes complex? How does the life of a complex organism differ from that of a simple organism?

CHAPTER VI

PROTOPLASM AND THE CELL

Problems:

1. What is the nature of the living substance?
2. What activities are common to living things?
3. To what extent are all living things similar?

Foreword. All of the early studies of plants and animals were limited to structures which could be seen with the unaided eye. Such studies had been pursued by Greek and Roman scientists, but had lagged during the period of mental stagnation which characterized the Middle Ages. Then a series of events transpired which were destined to give rise to the modern science of biology. These events had their origins in the invention of the microscope.

The microscope. In the early part of the seventeenth century the first compound microscopes were developed. A new world of microscopic life was now revealed to the eyes of scientists. One of the first workers to explore this field was Anton van Leeuwenhoek (1632–1723) of Holland. Leeuwenhoek discovered, among other things, such organisms as bacteria and protozoa. The next step was inevitable. Robert Hooke, of London, while examining a thin section of cork with one of the early microscopes, observed that the material was composed of many tiny box-like spaces which he called cells. This discovery was published in 1665. He studied other plant tissues and again found the box-like spaces. The structures which impressed him were in reality the cell walls, and not the living contents within these walls. However, a great step forward had been made, and Hooke is generally credited with the discovery of the cell. Robert Brown discovered the cell nucleus in 1833.

In 1838 and 1839 two Germans, Matthias Schleiden, a botanist, and Theodor Schwann, a zoologist, published results which showed that all organisms are made up of cells. They found that many-celled organisms may begin life as a single cell, which is destined to divide a number of times, thus giving rise to many cells. These discoveries resulted in what is now known as the "cell principle." It was not long until another German, Max Schultze (1861), showed that cells contained a living material which we call protoplasm.

THE LIVING SUBSTANCE IS PROTOPLASM

All organisms have certain likenesses of structure and function. We should not attempt to think of plants and animals as groups of organisms that are sharply separated from each other by obvious differences, because such is not the case. It is evident enough that a tree is a plant and that a dog is an animal. But some of the simpler forms of life are harder to classify. There are "border-line" organisms which exhibit characteristics of both plants and animals.

We ordinarily think of plants as organisms that are unable to move about. But some of the lower plants move about very actively. And many of the lower animals, such as some sponges, corals, oysters, and barnacles, are permanently attached when in the adult condition. We also have noted that green plants contain the green-colored substance chlorophyll, but some plants, such as fungi, do not contain this material.

Protoplasm. Today we recognize that plants and animals have at least one thing in common. They are made up of protoplasm, which has been called "the physical basis of life."

Appearance of protoplasm. When viewed with the aid of the microscope, living protoplasm appears as a semitransparent, liquid substance, containing granules. It seems to consist of a basic liquid in which portions of a denser nature are suspended, which give it a jelly-like property. The denser material may appear in the form of globules, or fibers, or a mesh-like network. Protoplasm varies in appearance and chemical composition. It is not identical in different species, or even in different cells of the same body.

Elements in protoplasm. Chemists now recognize ninety-two substances called elements. These simple substances are composed of minute particles known as atoms. Atoms have capacities for uniting with each other in definite proportions. The union of two or more atoms in definite proportions results in a molecule. If a molecule is made up of the atoms of different elements, it represents a compound. For instance, a drop of water consists of many molecules, each of which is composed of two atoms of hydrogen and one atom of oxygen. We recognize water as a compound, composed of the elements hydrogen and oxygen.

Protoplasm is made up of common elements. These are carbon, hydrogen, oxygen, and nitrogen, together with smaller amounts of such elements as phosphorus, sulphur, iron, chlorine, potassium, magnesium, sodium, and calcium. It should be noted that these elements are not peculiar to living things. They are found about us in the inorganic world. Obviously, the secret of life is not so much a matter of the elements which compose protoplasm, as it is the ways in which these elements are combined.

The elements in protoplasm are organized to form compounds. We find among the compounds within protoplasm such substances as proteins, carbohydrates, fats, water, and inorganic salts.

Proteins. There are many different kinds of proteins, and all of them are complex chemical compounds. Common examples of foods that contain large proportions of proteins are eggs and lean meat. While we usually think of eggs and meat as foods, a moment's reflection tells us that their origins are in living things. Proteins always contain carbon, hydrogen, oxygen, and nitrogen, and usually small amounts of sulphur and phosphorus. They make up the greater part of the living cell, but proteins cannot live alone — the other compounds of protoplasm must be present.

Carbohydrates. Carbohydrates contain carbon, hydrogen, and oxygen. The hydrogen and oxygen usually are in the ratio of two atoms of hydrogen to one atom of oxygen. They are not as complex chemically as are the proteins. The sugar glucose, with the chemical formula $C_6H_{12}O_6$, and starch $(C_6H_{10}O_5)_n$, are carbohydrates.

Fats. Fats, like carbohydrates, are composed of carbon, hydrogen, and oxygen. The H and O, however, are not present in the ratio of two atoms of hydrogen to one atom of oxygen. Fats contain relatively less oxygen than do carbohydrates, and therefore have a greater capacity for combining with oxygen (oxidation).

Inorganic salts and water. Inorganic salts such as sodium chloride or common salt (NaCl) and various other salts make up about one per cent of protoplasm. Water is present in varying amounts, from forty per cent to over ninety per cent. We have seen that water is very important to the organism. In addition to forming a part of protoplasm, it serves as a solution medium within the organism for digested food and for waste.

Enzymes and vitamins. Enzymes are chemical substances, secreted by various cells, that serve to produce chemical changes. Vitamins are supposed to be present in some kinds of protoplasm. They have been studied principally from the standpoint of diseased conditions which occur in their absence. They appear to be necessary to the well-being of organisms. Enzymes and vitamins will be considered in greater detail in later discussions.

ALL LIFE ACTIVITIES ARE EXHIBITED BY PROTOPLASM

Amœba. Amœba may be taken as an example in studying the properties of protoplasm, because Amœba is essentially a drop of protoplasm. It is an animal, a member of the protozoan group, which includes many of the least complex animals. However, Amœba is not the simplest form of life. It is not always common in a given locality. It is found, however, in many parts of the world, in both fresh water and salt water. It usually is less than one one-hundreth of an inch in diameter. There are several different species of this organism. The following description deals particularly with the species Amœba proteus.

Structure of Amœba. As will be seen in the accompanying diagram, the single cell which composes Amœba's body is divided into two general areas, the outer cytoplasm and the nucleus.

The nucleus can be distinguished from the cytoplasm because it is denser in appearance. The cytoplasm is practically colorless except for the particles of food and granules of foreign matter which may be included in it. The cytoplasm includes all of the cell except the nucleus. The contractile vacuole appears as a small, semitransparent spot in the cytoplasm. One or more food vacuoles may be present. We might assume that there would be a cell wall around the cytoplasm, as in the case of many cells. There is, however, none in the case of Amœba. When a portion of the cytoplasm is extended we have what is known as a pseudopodium (false foot). The cell as a whole is protoplasm; in other words, the nucleus and the cytoplasm are parts of the protoplasm.

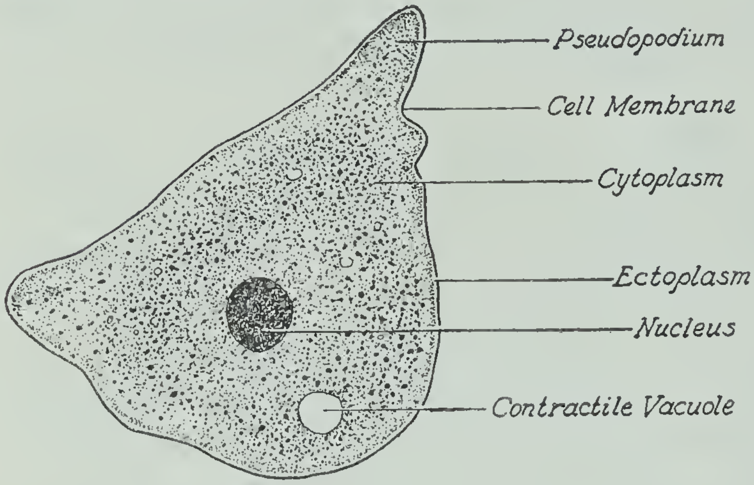

FIGURE 56. Diagram of an Amœba.

A study of Amœba's behavior reveals that it carries on a number of life activities. These may be referred to as functions. Since Amœba is a drop of protoplasm, to all intents and purposes, the activities of Amœba are activities of protoplasm.

Sensitivity. If an Amœba is resting quietly in a drop of water its sensitivity or irritability may be tested by placing in the water a small particle of some staining material such as methylene blue. As the stain diffuses through the water it will come into contact with the Amœba and the latter will move away. If the same experiment is repeated under the same conditions it will be found that the general results are the same. This indicates that the organism is capable of receiving and responding to external stimuli. In other words, it is sensitive.

Locomotion. There are various theories concerning the manner in which Amœba moves from place to place. We shall not attempt to study these theories in detail but simply shall state the observed fact that Amœba "moves by means of pseudopodia." A pseudopodium is extended, and the protoplasm flows into it as the posterior end of the cell contracts.[1] The result is locomotion. Pseudopodia are not permanent in form, or in position, and various changes in the shape of the cell result from expansion and contraction. The important point involved here is that protoplasm has the ability to contract.

Digestion and assimilation. Amœba "eats" and digests smaller organisms. As we have noted in the first unit, it may be cannibalistic, the larger Amœbæ "eating" the smaller individuals. When an Amœba comes in contact with a food particle, the protoplasm flows outward, forming a pocket around the food. Then the extensions of protoplasm join, and the food is inside the cell. This "eating" process is called ingestion. An organic particle, together with the drop of water that is ingested with it, makes up a food vacuole. Such an organic particle is acted upon by enzymes. In this case the enzymes are digestive fluids secreted into the food vacuole by the surrounding protoplasm. The enzymes dissolve or digest the organic particle. Some of the resulting materials are then ready to become part of the protoplasm. This final process of becoming part of the protoplasm is known as assimilation.

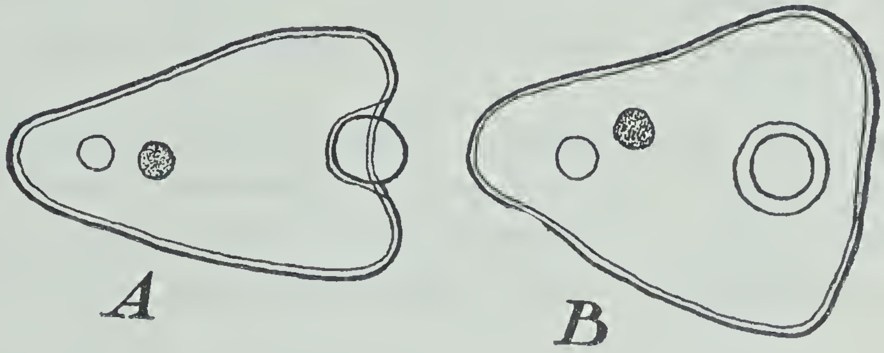

FIGURE 57. Diagram of an Amœba ingesting a food particle.

Waste disposal. There is another problem to be considered in this study of protoplasm, namely, how organisms dispose of wastes. We may assume that waste materials in the case of Amœba are of three kinds; gases, liquids, and solids. The gaseous wastes are disposed of in the process of respiration, which involves taking oxygen into the cell and discharging carbon dioxide. It has been suggested that some carbon dioxide waste may be discharged by the contractile vacuoles. Solid wastes are accumulated in the cytoplasm and eventually break through the cell membrane to the exterior.

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[1] There are other theories as to the exact method of locomotion in Amœba.

Excess liquids gather as small drops in the cytoplasm; these masses of liquid make up the contractile vacuoles. The liquids probably contain some dissolved carbon dioxide and liquid waste. When a mass of such waste has been accumulated the surrounding cytoplasm contracts and the waste is forced out of the cell. Contractile vacuoles vary in position and number. Their main function seems to be to regulate the water content of the cell.

Growth and reproduction. Assimilation is often followed by growth in size. The cell does not continue to grow without end. When it reaches a certain size it divides into two approximately equal parts. This is Amœba's method of reproduction.

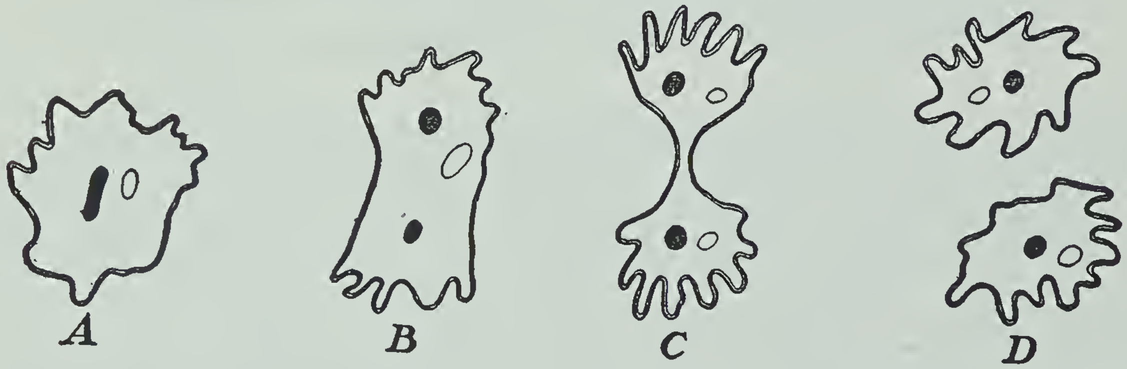

FIGURE 58. Diagram illustrating simple fission in Amœba. *A* shows the nucleus elongating; the nucleus is divided in *B*; in *C* the cytoplasm is dividing; *D* shows the two daughter cells.

First the nucleus divides into two parts. Then the cytoplasm divides in such a manner that half of it goes with each nucleus. Each new cell resulting from this process is one half as large as the parent cell. The type of reproduction represented here is known as simple fission. If conditions of life are favorable, the two newly produced Amœbæ will grow and divide in turn. It will be observed that there is no "natural" death, like that found among higher animals, in the life cycle of Amœba. Many Amœbæ are killed by external agencies however. There sometimes is a period of inactivity at the end of the life cycle that may correspond to a period of "old age." Then new cells are formed and the life cycle begins again.

A green alga. Let us now examine briefly the structure and some of the activities of a rather simple plant cell. For this purpose we may use Closterium (a desmid), which belongs to the group of plants known as the green algæ. Many other single-celled green algæ would serve our purposes equally well.

Closterium is a small organism found in the water. When we refer to the accompanying diagram we observe that it is crescent-like in shape. Unlike Amœba, this plant cell has a definite cell wall that covers its outer surface. Within the cell we observe several structures or regions, some of which were not seen in the case of Amœba. The area of the cytoplasm, for instance, includes the structures known as chloroplastids. These bodies contain the green-colored material chlorophyll. Chlorophyll, as will be seen, is of great importance in the process of food-making.

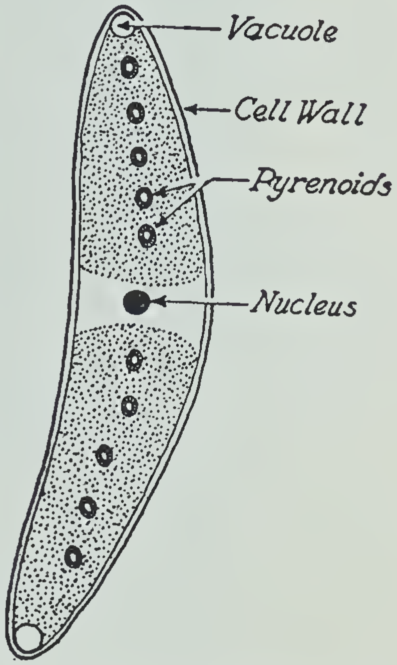

FIGURE 59. Diagram of Closterium — a green alga.

Other structures found in the cytoplasm are the pyrenoids and the vacuoles. The pyrenoids may have some function in the food-making process. The vacuoles of Closterium appear as circular drops of liquid at the opposite ends of the cell. The nucleus is a small, roughly spherical body. It lies in a transparent area of the cytoplasm near the mid-region of the cell.

Closterium carries on most of the life functions that we have observed in the case of Amœba. It consists of protoplasm, and is alive. In two respects, however, its activities differ from those of Amœba. First, it does not move about as a result of its own efforts, and second, it has the ability to manufacture food.

Photosynthesis. Being a green plant cell, Closterium is able to make food or carry on the process of photosynthesis. In this process, the green plant cell, utilizing sunlight as a source of energy, manufactures simple sugar from carbon dioxide and water. Oxygen is produced as a by-product. Sugar is an organic compound — a food, whereas water and carbon dioxide are inorganic compounds.

This reaction cannot be performed in the typical animal cell, since it depends upon the presence of chlorophyll. The fact that the energy for photosynthesis comes from sunlight explains why green plants of many species fail to grow in shaded localities. Without sufficient sunlight they are unable to manufacture the necessary food.

Sugar, such as glucose, is the basic food substance. The foregoing reaction, then, is of the greatest importance. In this reaction we find the origin of the food available to most living things.

Metabolism. All of the foregoing processes — sensitivity, contraction, assimilation, excretion, respiration, growth, reproduction, and food manufacture — may be illustrated by the study of simple, single-celled forms of life. These processes represent life functions, or we may say that, taken together, they are metabolism. For metabolism is defined as all of the processes that are carried on by or within the organism.

Anabolism and katabolism. Metabolism has two phases. One is the building-up process, which is called anabolism. Anabolism is the dominant process in youth, when the organism is growing rapidly. The tearing-down process is katabolism, which goes on throughout the life of the organism, and becomes dominant during old age. In fact, life may be viewed as a contest between anabolism and katabolism. When anabolism is most active, growth and probably reproduction take place. When katabolism becomes dominant, it usually is accompanied by decline and approaching death.

It also is worthy of note that protoplasm, represented by simple cells such as Amœba and Closterium, is able to carry on all of the basic life processes. To be sure, excretion is a more complex process in the human body. So are digestion, assimilation, and other living functions. Nevertheless, they are present, in simple form, in the living activities of the single-celled organisms.

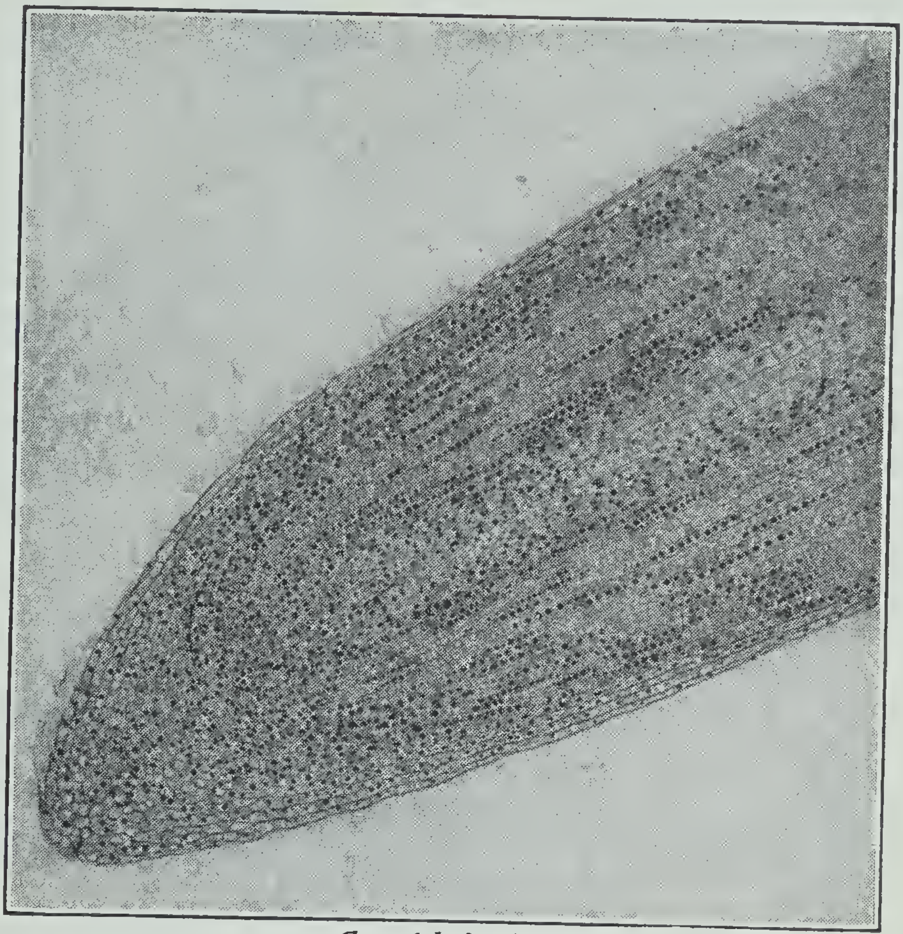

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FIGURE 60. Photomicrograph of a section through a root tip, showing cellular nature of the material.

LIVING THINGS ARE MADE UP OF CELLS

The cell concept. We have seen that Amœba and Closterium are single-celled organisms. Many other forms of life are of this type. When we examine the bodies of large plants and animals we find that they consist of many cells, together with materials that have been secreted by these cells. The human body, for instance, is made up of many cells, which co-operate to perform the various life functions. A section of a plant root or leaf, when viewed with the aid of a microscope, is seen to be composed of many cells. We say, therefore, that the cell is the unit of structure. This is the basic principle of the so-called "cell concept." This concept holds that all plants and animals are made up of cells, and that all activities of these plants and animals are the sum of the activities of the cells.

Every organism develops from a single cell. Other studies have shown that some structures in complex organisms are not composed of cells, but are manufactured by cells. Such tissues as bone and cartilage are only partially composed of cells, but the other materials in them are secreted by cells, and so are of cellular origin. The study of development has shown that no matter how complex the adult body of an animal may be, it usually comes from a single cell. Of course it is understood that some of the lower organisms may regenerate complete bodies from certain parts of bodies. In all cases development, or replacement of parts, depends upon the production of new cells by cell division.

Size of cells. Cells vary greatly in size and shape. Most of them are very small, and cannot be seen without the aid of a microscope. Some are so small as to be barely visible when viewed with the best lenses that man has been able to produce. Some human nerve cells present an interesting case because, while they are several feet long, they are so slender that they are invisible to the unaided eye.

On the other hand, some cells are visible without the aid of lenses. Paramecium caudatum, a protozoan, although small, may be seen by the unaided eye, especially when colored by a little staining material. A hen's egg is a single cell, greatly enlarged by the presence of stored food.

Shape of cells. The shape of cells probably depends upon function and upon pressure. Some simple types of cells are spherical in shape. Yet certain cells must have other form if they are to perform their functions in an efficient way. A muscle cell, for instance, must be elongated if it is to contract effectively. And certainly pressure, in the bodies of the larger organisms, has some effect upon the shapes of cells.

As we have learned in studying Amœba, the cell may be divided into two general regions, the cytoplasm and the nucleus.

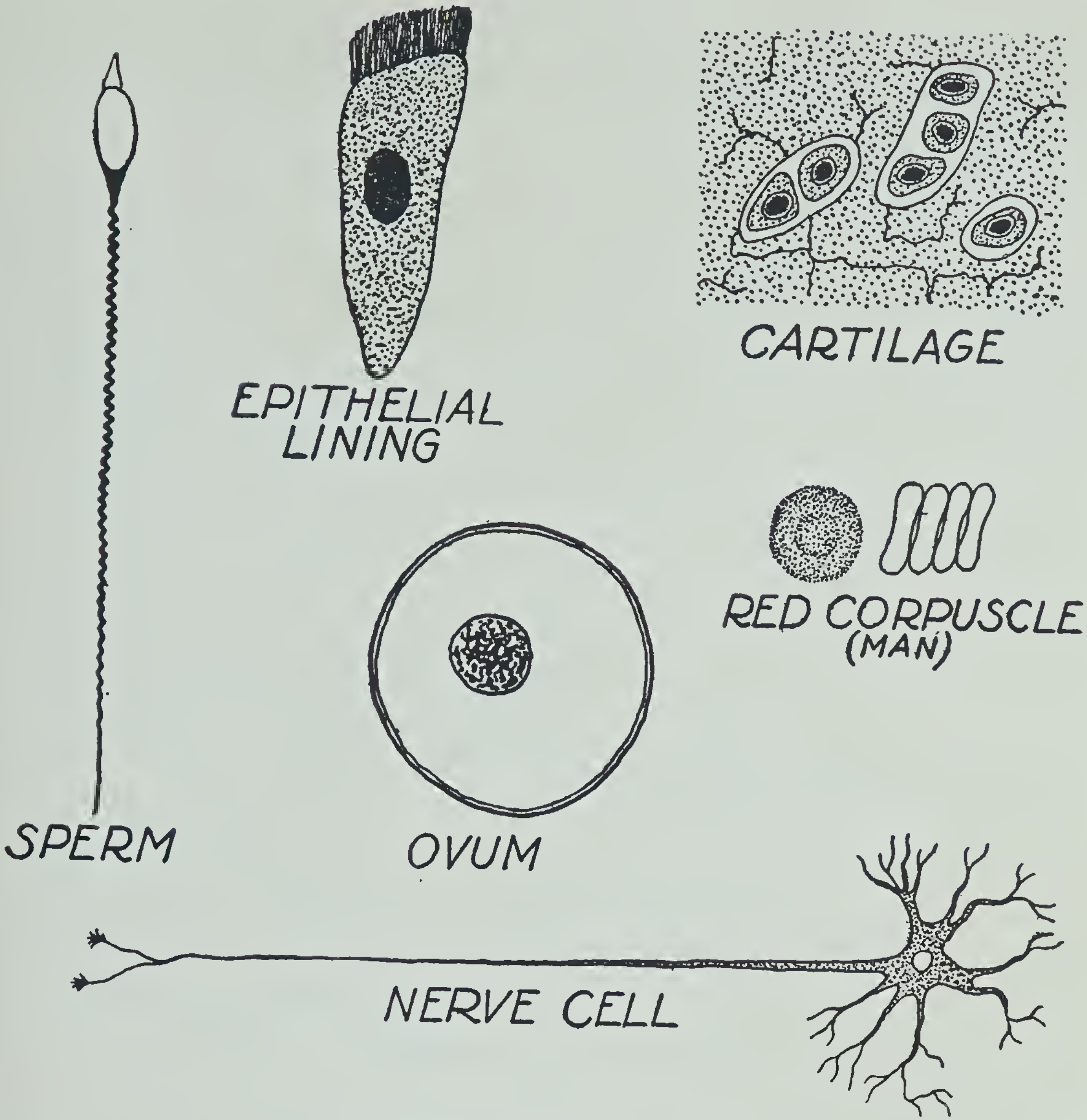

FIGURE 61. Types of cells.

The cytoplasm is the outer, more transparent area, and the nucleus lies within it.

The cytoplasm. The cytoplasm of the typical animal cell often contains food vacuoles, contractile vacuoles, and granular material. The first two structures mentioned have already been discussed under the subject of Amœba. The granular material may represent stored food, or in some cases, solid waste materials. The cytoplasm of the plant cell (green plant) is marked by the presence of chloroplastids. Other bodies known as pyrenoids are present in some kinds of plants. In the case of plant cells the cytoplasm may also contain vacuoles of cell sap.

The cell membrane. In both plant and animal cells, a thin membrane, the cell membrane or plasma membrane, forms the outer boundary of the cytoplasm. This membrane is a living part of the cell.

The cell wall. The cell wall, when present, forms a lifeless covering for the cell. Although it is non-living it is secreted by the cell. Plant cells often have rather heavy cell walls containing the material called cellulose. When the outer covering of a cell is thick it is of course necessary that there be some special provision for the entrance and exit of materials passing into and from the cell. To this end the cell wall may be porous.

The nucleus. The nucleus is typically rounded or spherical in shape, but this is subject to a great deal of variation in different species of plants and animals. It is surrounded by a membrane, called the nuclear membrane. Certain material within the nucleus is called chromatin. In later studies it will be found that chromatin is important because of its relationship to heredity.

It perhaps should be mentioned in passing that some cells appear to have no nuclei at certain times. The mature red corpuscles of human blood furnish an example. On the other hand, some cells contain more than one nucleus, as in the case of the striated muscle cell of man. In this latter instance it has been suggested that each "cell" represents a fusion of two or more cells.

The unity of life. In summary, we see that there is a unity of life, or a basic similarity of living things. In the first place, living things are made up of cells. Secondly, cells contain the living substance protoplasm. Finally, all living things perform certain functions which are typical of protoplasm. It is true that the green plant alone can make sugar from carbon dioxide and water. Yet all animals and all plants must have food for purposes of growth and repair.

SUGGESTED ACTIVITIES

Scientific methods

A scientist uses mechanical tools such as the microscope and the balance to assist in observation and measurement.

1. Examine a microscopic slide bearing stained Amœbæ, with the aid of the compound microscope. Your instructor will explain the use of the microscope. (Compare the Amœbæ with Figure 56 in the text.) Identify the nucleus, cytoplasm, the cell membrane, and extensions of the cytoplasm that might be regarded as pseudopodia. Prepare three or four labeled sketches to illustrate general structure and variation in shape.
2. If a culture containing Amœbæ is available, place a drop of the culture on a glass slide. Cover the drop with a cover glass, resting the latter upon small, broken pieces of another cover glass. Examine the material with the aid of a compound microscope. It may be necessary to obtain several samples of the culture material before an Amœba is found. Observe and report upon the animal's behavior in locomotion and the ingestion of food. If possible, locate a contractile vacuole, and observe its behavior.
3. Using a prepared microscopic slide of Closterium, study its structure with the aid of a microscope, and identify the structures indicated in Figure 59. Prepare a labeled sketch.
4. If a slide of Closterium is not available, some Spirogyra, obtained from a fresh-water pond, may be substituted. Place a few filaments on a slide, cover with a cover glass, and examine the material with the aid of a microscope. Prepared slides of Spirogyra also may be used. In this type the chloroplast has a spiral arrangement.
5. Examine a thin section of cork with the aid of a microscope. Prepare a sketch of what you see, and relate it to the story of Hooke's discovery of cells.
6. Examine a microscopic slide of a root tip (onion suggested) with the aid of a microscope. Identify individual cells. Prepare a sketch of the section. Do the same thing in the case of some animal structure, such as a section of Hydra, or a section of liver tissue.
7. With the aid of a microscope, examine a section of cartilage. Locate the cells in the section. Discuss their relationships to the other material, which is called intercellular substance.
8. In *Microbe Hunters*, by De Kruif, read about Leeuwenhoek. Write an account of his microscope, and the things that he was able to see with this instrument.
9. After consulting the reading references at the end of this chapter, prepare a chart for demonstration purposes, illustrating different kinds of cells found among plants and animals.

SUMMARY OF PRINCIPLES

1. Protoplasm is the living material of all cells.

2. Protoplasm is composed largely of the common elements, hydrogen, carbon, oxygen, and nitrogen, combined to form various compounds.
3. Protoplasm is made up of such compounds as proteins, carbohydrates, fats, water, and inorganic salts.
4. All organisms exhibit the functions of irritability, contractility, assimilation, respiration, excretion, and reproduction.
5. Green plants make foods from carbon dioxide and water; sunlight furnishes the energy for this process.
6. Metabolism refers to all of the processes that function within the living organism. It has two phases:
    a. The building-up process or anabolism.
    b. The breaking down process or katabolism.
7. The cell is the structural unit of all plants and animals.
8. Cells vary greatly in size and shape.
9. All organisms have fundamental similarities.

GUIDE QUESTIONS

1. What is the "physical basis of life"?
2. Name six functions of protoplasm.
3. Draw a sketch of Amœba showing five important structures.
4. What one important process can be performed by Closterium but not by Amœba?
5. What is the source of the energy for photosynthesis?
6. Draw a sketch of Closterium showing four important structures.
7. Name four contributors to our knowledge of the cell and state the contribution of each.
8. Define metabolism.
9. What are the two contrasting processes involved in metabolism?
10. Name two respects in which all plants and all animals are alike.

BOOKS TO READ

Hegner, R. W. *College Zoology.*
Mavor, J. W. *General Biology.*
Plunkett, C. R. *Outlines of Modern Biology.*
Smith, G. M., and others. *Textbook of General Botany.*
Woodruff, L. L. *Foundations of Biology.*

CHAPTER VII

SIMPLE PLANTS AND ANIMALS

Problems:

1. What are the structures of the simpler plants and animals?
2. Do any of these simpler types show a tendency toward the development of special cells or special functions?

Foreword. Our study of protoplasm and the cell furnishes us with some basic facts about the unity of life. We can now investigate another matter, the diversity of life, or the differences which exist among living things. How has it come about that there are so many kinds of organisms? In this and the following chapters we shall see how cells are combined to form bodies of greater complexity. We shall begin our study with the simpler or lower plants and animals, and proceed to a discussion of species that are more complex in structure.

Let us again examine some of the organisms found in pond water. We may collect our material in a shallow place near the shore. In dipping water from the pond we shall include some decaying leaves, sticks, stems, and even mud from the bottom, and some of the algæ that form a green scum upon the surface. Our material is placed in a glass jar and taken to the laboratory for study.

We now place a drop of this pond water upon a glass slide, and cover it with a cover glass. It then may be examined with the aid of a microscope. Probably we shall see many bits of decaying plant material, but in addition there may be living plants and animals. Green, single-celled algæ are probably present, and in some cases the cells may be joined together to form filaments. Numerous small animals may be seen, and many of these will be single-celled protozoa. One of the common types of protozoa is Paramecium.

PARAMECIUM

(An animal that is specialized in one-celled structure)

Paramecium. Paramecium is the name of a genus which includes a number of species. The following description refers particularly to the species P. caudatum.

Structure of Paramecium. P. caudatum has a more or less permanent shape, being oval, with one end of the cell slightly more rounded than the other end. The rounded end is considered to be the anterior (front or head) end of the cell. As will be seen in the accompanying diagram, Paramecium has an outer, transparent covering that is called the cuticle (pellicle). Small structures known as trichocysts are found just beneath the cuticle. These trichocysts may be discharged under certain conditions; they are supposed to serve as defense or offense structures.

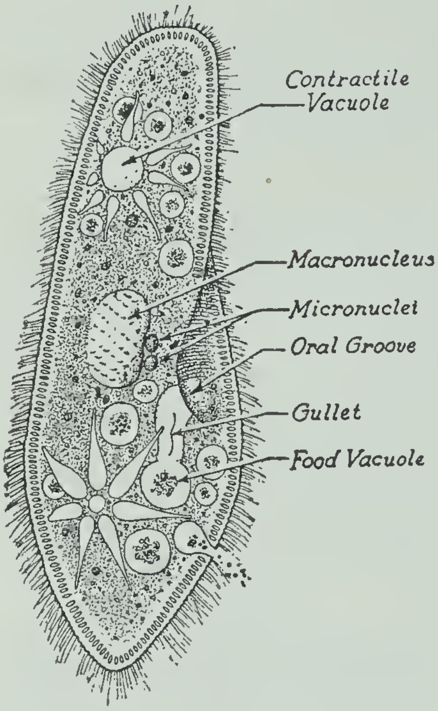

FIGURE 62. Diagram of a Paramecium. Which is the so-called "anterior" end?

An oral groove appears as a depression in the surface of the cell. which leads inward to the mouth opening. There are two permanent contractile vacuoles, one at either end of the cell. Small channels in the cytoplasm carry liquids to the contractile vacuoles. The cell has two nuclei, one of them distinctly smaller than the other.

Motion. The development of cilia is one of the interesting features of this animal's structure. In Paramecium the cilia cover the body and even extend down into the oral groove. They are capable of rapid motion and one of their functions is to propel the animal through the water.

Digestion. In the region of the oral groove the cilia have a special function; they wash water containing food particles into the cell through the mouth opening. Food consists of small organisms, mostly bacteria and other single-celled plants. The cytoplasm contains the usual food vacuoles in which food particles are digested by the action of enzymes. Digested food is absorbed by the surrounding protoplasm.

Excretion. Excess liquids are discharged by the contractile vacuoles. Some liquid and gaseous wastes may be included. Solid wastes tend to break through in one special region, sometimes referred to as the anal spot, where the cuticle appears to be weak. As in Amœba, respiration involves taking oxygen into the cell, and the discharge of carbon dioxide.

Reproduction. Reproduction in Paramecium is similar to that of Amœba, but is not the same in all respects. The nuclei elongate and divide to form daughter nuclei. A second oral groove and two new contractile vacuoles are formed. Then the cytoplasm divides through the mid-region (short axis) of the cell and two daughter cells result.

This type of reproduction will continue for a number of generations. The process may eventually slow down, however, and then conjugation usually takes place before active division and growth are resumed. In conjugation two Paramecia come together until their cuticles are in contact with each other. An exchange of material of the two small nuclei (micronuclei) takes place. Then the cells separate again and each one apparently is once more capable of resuming active growth and division. This addition to the process of reproduction is interesting because it suggests the development of sex.

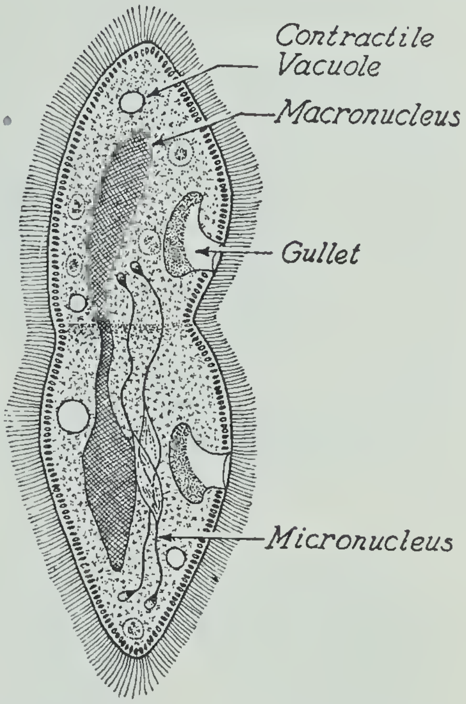

FIGURE 63. Diagram of a Paramecium in the process of division (transverse fission).

Summary. We may observe that in Paramecium certain parts of the protoplasm carry out certain functions. This is a case of division of labor within a single cell. We note in addition that Paramecium has structures not possessed by Amœba. Such structures include cilia, a mouth opening, an anal spot, trichocysts, and permanent contractile vacuoles. It might be suggested that Paramecium is a more specialized type of animal than Amœba — it has become specialized in one-celled structure.

ALGÆ

(Various species exhibit adaptations for food-making, attachment, locomotion, and reproduction)

Single-celled plants. Many one-celled plants may be found among the green scums. Some of these, like Closterium, are found in fresh water. Others are found in salt water, and a number of them live in moist places on the land. They belong to the group of plants known as the algæ. The aquatic types, both in the sea and in fresh water, make up a large part of plankton.

Pleurococcus. Pleurococcus is an alga that lives in moist places on the shaded sides of trees and rocks. We may obtain samples for study by scraping some of the green film from the moist bark of a tree.

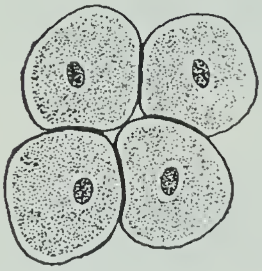

FIGURE 64. Diagram of Pleurococcus — a group of individuals.

Single specimens are tiny, spherical cells. Each has a cell wall largely composed of the material cellulose. Within the cell wall, the cytoplasm, a large chloroplastid and a nucleus may be seen. The chloroplastid contains the substance chlorophyll. Furnished with light, moisture, and a surface from which necessary chemical compounds can be absorbed, each cell can manufacture its own food by photosynthesis. Each cell carries on its own life functions, independent of other cells. No locomotion is necessary.

In one particular, Pleurococcus suggests how more complex organisms may develop. Reproduction is the result of simple cell division. Under favorable conditions each cell may divide to form two daughter cells, and these two cells may each divide again, thus forming four. When the daughter cells remain attached to each other, as is frequently the case, groups of two, four, or as many as thirty-two individuals form a "colony." Each cell, however, continues to carry on all of its own life activities as an independent unit.

Filamentous algæ. A number of algæ form filaments consisting of cells joined end to end. Two of these, Spirogyra and Ulothrix, may often be found in fresh-water habitats.

Spirogyra. Spirogyra is found floating upon the surface of ponds and streams. When viewed under the microscope, its chloroplast shows a spiral form as will be seen in the accompanying figure. The cells of a filament are joined end to end to form an attached group. Each cell, however, is a typical green alga, which carries on its life functions including food-making without aid from other cells of the filament.

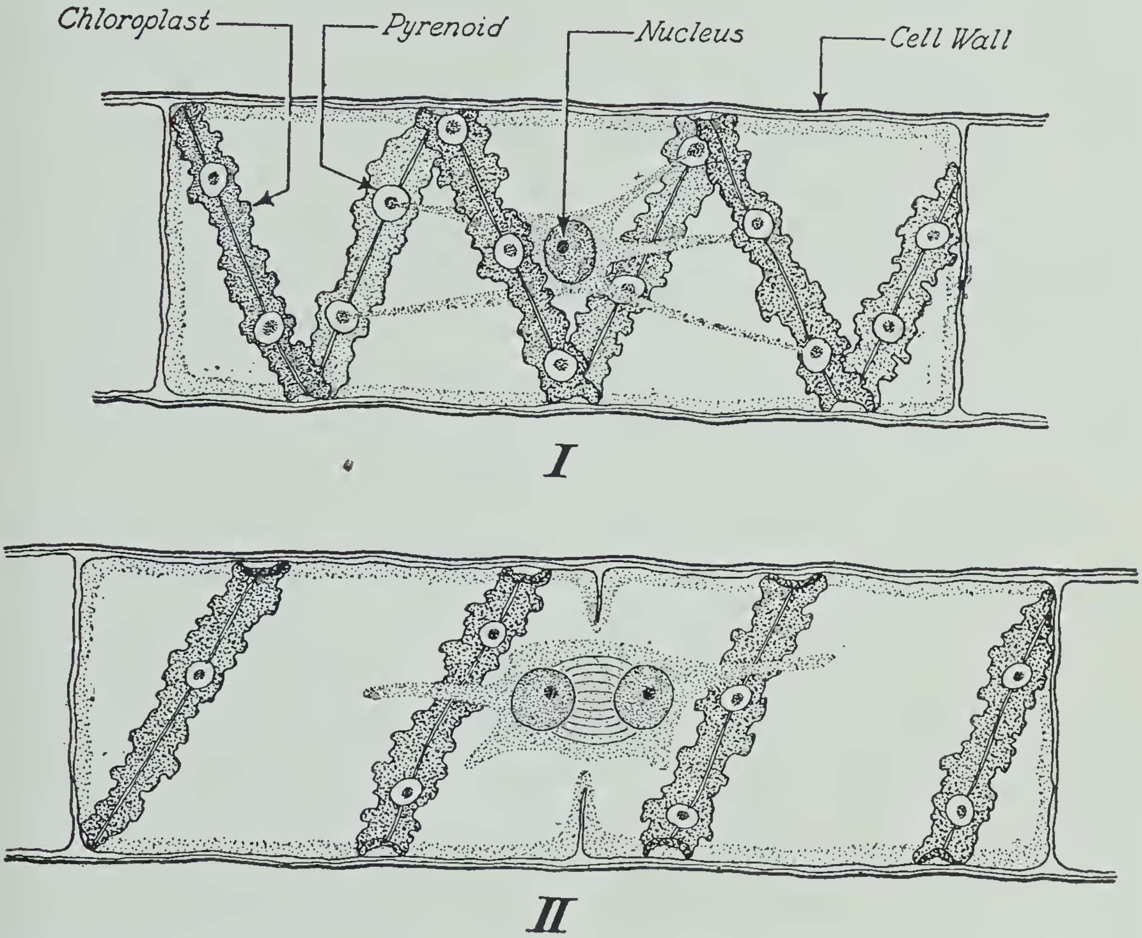

FIGURE 65. Diagram of Spirogyra. I, a single cell; II, a cell dividing.

As the cells divide, the filament becomes longer and contains more cells. But there is another phase in the reproduction process. Sometimes two filaments come close together and adjoining cells swell until their cell walls touch each other. The cell walls dissolve in part, and the contents of a pair of cells will be merged in one special cell. After a resting period, such a special cell may begin the development of a new filament by division and subdivision.

Ulothrix. Another special adaptation appears in the case of Ulothrix, which is found in fresh-water springs and streams. Ulothrix develops filaments of cells similar to those of Spirogyra. As in Spirogyra, a filament is formed by repeated cell divisions. In Ulothrix, one cell (or more), of a filament adheres to some solid object in the water, thus anchoring the filament in one place. This leaves the upper part of the filament free to sway with the water currents and to grow toward the sunlight. The modified cell (or cells), used as a "hold-fast" is called a "rhizoid." Such a cell is without chlorophyll and cannot manufacture food. It is dependent for nourishment upon other cells of the colony. All of the other cells, however, perform their own life functions, except possibly in the case of reproduction.

At intervals a change occurs in some cells of a Ulothrix filament. The contents of these cells divide to form several smaller, oval cells which bear flagella. The cell walls break open and these small cells escape into the water. A number of these cells may now be seen to have four flagella; they settle down upon some surface and begin to develop new colonies by repeated division. Other smaller cells bear only two flagella, and some of these seem unable to form new filaments directly. Two of them, however, may unite, producing a larger cell, which then passes through a resting stage. Later on this large cell produces several swarm spores, which in turn may give origin to new Ulothrix filaments.

Spores and gametes. Spores and gametes are modified cells that have to do with reproduction. Ordinarily a spore is able to produce a new individual without first uniting with another cell. We have seen that some special reproductory cells must first unite in pairs before new individuals may be produced. Such cells are called gametes. The origin of spores and gametes represents a type of adaptation and a specialization for the process of reproduction.

Fucus. The "rockweed" is a familiar seaweed on both the Atlantic and Pacific Coasts of North America. It is Fucus, an alga which exhibits further specialization. Fucus develops a branching body, sometimes many feet in length. It is composed of many cells, but no leaves, stems, roots, or conducting structures are developed. To this simple form of body the name thallus is given. The "higher algæ" develop simple or branching thalli.

Fucus shows several advances by way of division of labor among the cells. The following are included:

1. Some cells are grouped to form hollow, air-filled balls, which act as floats and keep the thallus upright in the water.
2. A thickening of cells in the center of the thallus forms a sort of "rib."
3. Cells at the ends of the branches are the ones which undergo division.
4. Cells on the outer surface contain relatively more chlorophyll.
5. A "hold-fast" of many cells is developed at the lower end of the plant.

At the tips of some of its branches Fucus has special cells modified for purposes of reproduction. Such cells are included in a bladder-like structure, which also functions in holding the plant erect in the water. Within some of these bladder-like structures tiny male gametes bearing flagella are found. Others contain female gametes. The male gametes break free and swim about in the water. One of them may unite with a female gamete which has floated free into the water. The result is a cell known as a zygote. This union of a male gamete and a female gamete is known as fertilization. The zygote begins to develop and a new plant is produced by repeated cell division.

Kinds of algæ. Algæ of the many-celled variety may grow to a length of several hundred feet as in the cases of Sargassum and the great kelps of the Pacific. These thallus structures, held to the water surface by air sacs, expose great areas to sun-

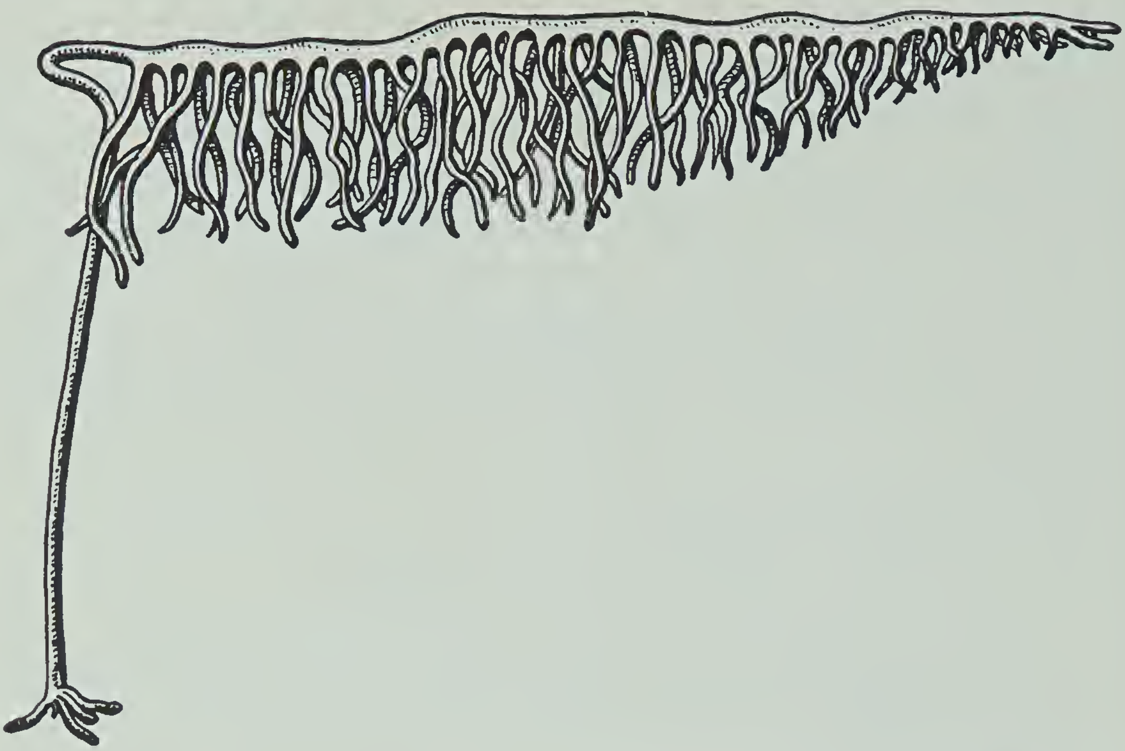

FIGURE 66. Diagram of a kelp — an alga which lives in the sea. Of what advantage to the plant is the spreading thallus?

light. Hence the manufacture of food is carried on by a great many of the cells. Four classes of algæ usually are recognized.

1. Blue-green algæ.
2. Green algæ.
3. Brown algæ.
4. Red algæ.

Summary. We have seen that algæ are aquatic or semi-aquatic plants, at least in most cases. All of them are food-making plants, containing chlorophyll. Some species are single-celled structures, others develop as groups of cells. In some cases, there is a beginning of division of labor among the cells. Even among these simple forms of plant life we find special adaptations for obtaining food, for attachment, for locomotion, and for purposes of reproduction.

VOLVOX

(A colonial type which exhibits division of labor among cells)

Volvox is another inhabitant of fresh-water ponds but may not be so easy to obtain as are Paramecium and Spirogyra. It sometimes is classified as an animal (colonial protozoan), but it also has been called a plant (green alga). A good many of the simpler forms of life are border-line types — they are difficult to classify, either as plants or as animals.

Structure of Volvox. A Volvox colony may consist of as many as 12,000 cells. The great majority of these cells bear flagella.[1] The colony is able to move about in the water with a revolving motion by virtue of lashing its flagella back and forth. To this extent there is a sort of co-operation on the part of the cells. The cells of the colony are connected by fine threads of protoplasm. Most of the cells, however, carry on their own life activities independently of the rest.

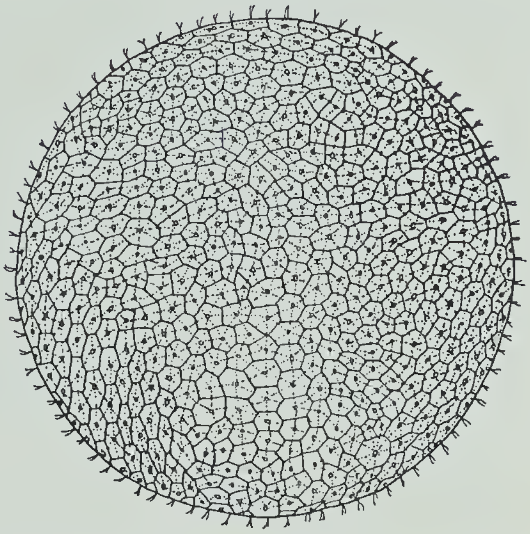

FIGURE 67. Diagram of a Volvox (special reproductory cells not shown).

Reproduction. A few cells of a Volvox colony show specialization of function. These develop into primitive sex cells; some of them give rise to sperms and others become egg cells. The sperms break away from the colony and may unite with the egg cells. The latter then become fertilized egg cells or zygotes. Zygotes develop into new, independent colonies through the formation of a group of flagellate[2] cells. Such colonies often develop inside the mother colony.

Summary. Volvox shows a division of labor in that a few cells become sperms and egg cells. As in the case of colonial algæ, one of the first signs of specialization involves the development of special reproductory cells.

Some general principles. Spirogyra and Ulothrix are filaments of cells, or simple plant communities. Volvox is a colonial organism. We now are able to make three useful generalizations with reference to the simpler plants and animals:

1. Single cells form new cells by division.

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[1] Called cilia by some writers.

[2] Cells which bear flagella.

2. Colonies result when the cells produced by successive divisions remain together.
3. Division of labor in colonies or filaments usually is shown first by cells modified for the function of reproduction.

MOST FUNGI ARE UNABLE TO MANUFACTURE FOOD

Bacteria. All of the simple plants that have been considered previously in this chapter are algæ. Another great group of simple organisms includes the bacteria, which sometimes are classified with the thallus plants and are considered to be fungi.[1] Bacteria are small in size; in fact, so small that even under highest magnification some of them can be seen only when staining material is applied to give them color. Yet they form an important part of the "unseen" world about us. They are found in ponds, streams, the sea, the air, and on the land. They may be present in our foods and some of them may live within our bodies.

Forms of bacteria. There are three general shapes of bacteria, as follows:

1. A spherical form called a coccus.
2. A rod-like form called a bacillus.
3. A twisted or spiral form called a spirillum.

The plurals of these words are cocci, bacilli, and spirilla.

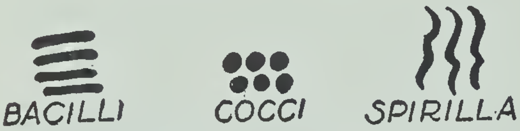

FIGURE 68. Types of bacteria.

Size of bacteria. Bacteria are very small. Some common forms, for instance, are about one twenty-five thousandth of an inch in length. It has been estimated that, in a teaspoon level full, five trillion average-sized bacteria could be accommodated. In milk that is souring, it is common to find one million bacteria per cubic centimeter (about one sixth of a teaspoonful). It is not uncommon to find as many as one billion in the same volume.

Structure of bacteria. Bacteria are single cells. Their extreme minuteness makes them difficult to study individually.

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[1] Some biologists classify bacteria as fungi; others do not. Even the inclusion of bacteria in the Plant Kingdom is sometimes questioned.

A bacterium has a cell wall, a cytoplasmic membrane, and a cell content of cytoplasm. Whether there is a special nuclear structure, or whether the whole cell acts in the capacity of a nucleus, remains to be determined. There is no chlorophyll. All food material must pass through the cell wall. The cytoplasmic membrane allows some materials to pass through and prevents the passage of others. Flagella are often present. The location and number of these flagella are so typical of some species that they help serve as means of identification. The function of these flagella is associated with locomotion.

Bacterial spores. Under adverse conditions, such as low temperature, absence of moisture, or lack of food (and sometimes under normal conditions), certain bacteria form spores. These spores are formed inside the cell. They appear to be associated with a shrinking of the cytoplasm, and a thickening of the cell wall. Sometimes the spore formation causes a swelling on one end of the cell, which results in a modified shape, similar to a drumstick. Among bacilli, many species form spores, among spirilla a few form spores, and among cocci no spore-forming species are known. Spores contain little water and often withstand unfavorable conditions of heat, cold, lack of moisture, and absence of food for a long time. When favorable conditions again appear they may revive and develop into bacterial cells.

Bacterial colonies. Bacteria multiply rapidly when moisture, food, and moderate temperatures are provided. On solid and semi-solid food materials this multiplication by simple cell division may result in the formation of colonies. Since the cells (except spherical types) subdivide across their longest diameters, chain-like formations are sometimes produced. These chains of bacteria may exude a sticky substance that covers the chain, to which the name sheath is given.

Bacteria multiply rapidly. Colonies of bacteria do not show any division of labor. Each cell "carries on" for itself alone. Bacteria, under favorable conditions, may subdivide as often as every thirty minutes. The colonies, therefore, enlarge in area and volume very rapidly. Simple calculation shows that at this rate, one bacterium, by successive subdivision, could produce a colony of about 17,000,000 in twelve hours. At the same rate, a mass as large as the earth might be produced in a few days. However, two conditions limit their multiplication:

1. Their food supply becomes insufficient.
2. Products of their own secretion accumulate and destroy them.

Types of bacteria. As we have said, bacteria are among the simplest forms of life. Always single-celled, without visible nuclei, without chlorophyll, reproducing by fission,[1] they exhibit very simple structures. Some need little or no air, although they must have oxygen, and therefore are called anærobic (without air). Bacteria differ markedly from the algæ because most bacteria are unable to manufacture food, and must live upon the materials of other organisms. Some bacteria feed on dead organisms and are called saprophytes. Others live at the expense of other living organisms and are called parasites.

Bacteria and human life. Bacteria are among man's worst enemies and best friends. Over 1000 species have been described, and probably many more remain to be discovered. We shall have occasion to refer to them again when we consider diseases and the economic aspects of biology.

Other fungi. Bacteria are not the only plants which lack chlorophyll. Other fungi are such types as the yeasts, molds, mildews, toadstools and mushrooms, rusts, and smuts. We shall direct our attention to some of their structures and activities.

Yeasts cause fermentation. You are familiar with yeast cakes. They are compressed masses of yeast plants mixed with a little starch paste. When placed in a dilute sugar solution containing a bit of protein and some mineral salts, the yeast plants begin to grow and reproduce. Ordinary fruit juices or molasses are suitable for the growth of yeasts. Their growth and reproduction is accompanied by a process called fermentation,[2] which yields carbon dioxide and

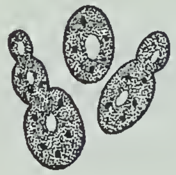

FIGURE 69. Yeast cells (diagram).

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[1] Recent work suggests that certain bacteria may reproduce in other ways.

[2] The growth and reproduction of some bacteria is also associated with a process called fermentation.

ordinary alcohol. Bread-making and wine-making depend upon this power of yeast to break up sugar.

Inspection of some yeast under the microscope will reveal that the material contains a number of single cells of different sizes, sometimes, but not usually, joined together in branching chains. Each cell has a cell wall, a nucleus, and a granular cytoplasm. Yeast cells reproduce in a manner similar to the process of fission, but differing in two particulars: (1) in yeast, a new cell is first formed as a small swelling or bud on the side of a parent cell — into this bud some of the parent nucleus flows; (2) then a cell wall grows up between the bud and the parent cell. Thereupon, this new cell absorbs its own food, and grows in size until it produces in time a bud of its own. This budding is characterized by one or more small daughter cells which form on the parent cell, and remain attached thereto for a time.

Molds. Many of us have observed that bread, potatoes, or almost any food material left in a damp, warm place will develop a grayish, cobweb-like, or furry coating in a few days. This is mold — a saprophytic, filamentous plant. A bit of the material examined first under a simple lens and then under a high-power microscope will reveal structures like those in the accompanying diagram.

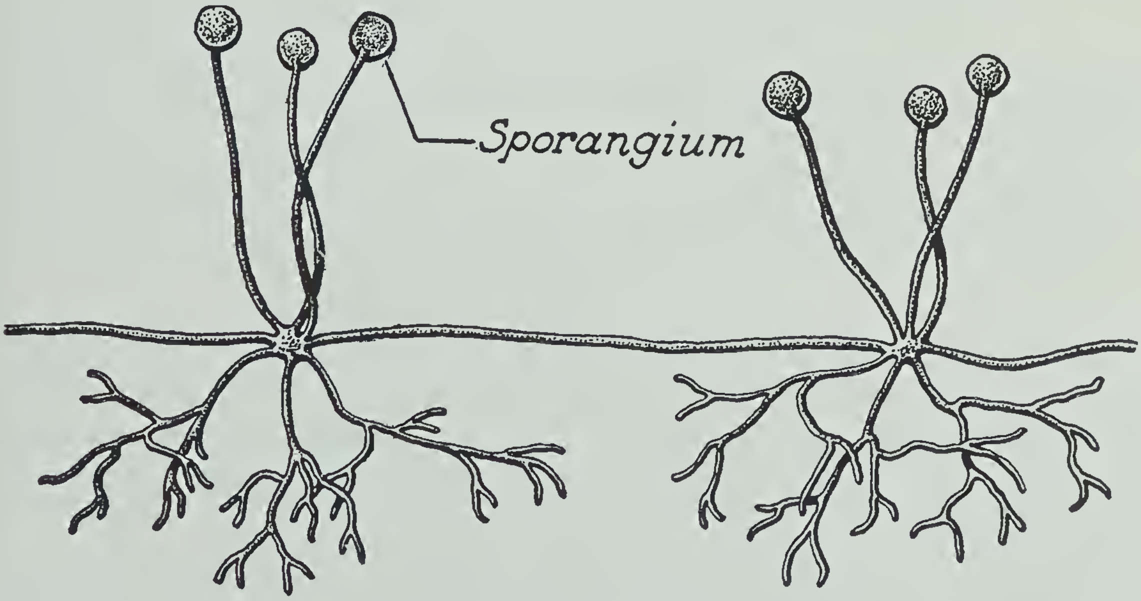

FIGURE 70. Diagram of a mold.

You will see branching networks of thread-like branches extending over and into the food. The whole mass of interlacing threads is called the mycelium, and each thread is a hypha. The hypha sometimes is an adaptation for absorbing food from the material upon which it rests.

Some molds form spore cases on the ends of branches which grow out of the mycelium. These spore cases grow larger and the contents break up into minute bodies or spores which float in the air. When they fall upon other food, each one may reproduce a new plant body with a mycelium and other spore cases. When different strains of some molds are brought together, they produce special reproductive cells that come into contact from adjacent hyphæ. This is similar to the process of conjugation we have observed in the case of Spirogyra.

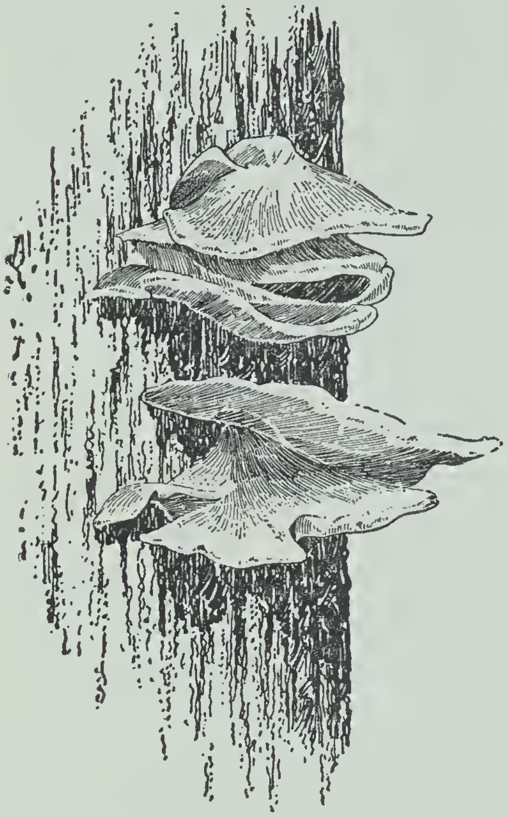

FIGURE 71. Fungi growing upon the trunk of a tree. Are they parasites or saprophytes? What other facts do you need in order to decide?

Mushrooms, smuts, etc. Mushrooms, toadstools, shelf fungi, puffballs, rusts, and smuts are names which refer to other types of fungi. All grow from a network of mycelial threads which draw nourishment from living or non-living organic material. Smuts and rusts are parasitic, the others are essentially saprophytic.

Wheat rust is interesting because it produces several kinds of spores, and spends part of its life cycle upon wheat, and another part upon barberry bushes. Pine-tree blister is also a rust which is parasitic upon two hosts, the white pine and currants or gooseberries.

Lichens. One group of organisms known as the lichens represent associations of algæ and fungi. These simple plants may often be seen in moist places upon trees and rocks, as patches of greenish scales. Sometimes as thin as paper, usually curled at the edges when dry, they often are very hard to remove from any surface upon which they are living.

Examination with a microscope shows that a lichen is a "partnership" of a fungus and an alga. Both profit somewhat. The alga manufactures food by photosynthesis. The fungus absorbs water and dissolved food materials from bark or even from rock surfaces. When two organisms live together, and both profit, the association is said to be a case of symbiosis.

Summary. We now have given attention to a number of relatively simple plants and animals. One of the first things that we have learned about them is that they are not equally simple in structure. Nor do all of them have identical functions. Paramecium is more complex than Amœba. Volvox, Ulothrix, and Fucus exhibit division of labor among cells. Most fungi are parasites or saprophytes, and no fungus contains chlorophyll. Algæ differ from fungi and from protozoa in that they contain chlorophyll, and are able to manufacture their foods from inorganic compounds. We begin to realize that while organisms have basic similarities, they also develop many noticeable differences.

SUGGESTED ACTIVITIES

Scientific methods

a. A scientist makes his records at the time that he observes the facts.

b. A scientist labels samples and specimens as to source, date, and other important facts.

1. Perform the examination of pond water suggested on page 113. Identify different types of algæ and protozoa.
2. With the aid of the microscope, examine microscope slides bearing Paramecium. Refer to Figure 62 in the text, and identify the cuticle, the oral groove, the nuclei, and possibly other structures which may be seen. Prepare a labeled sketch.
3. With the aid of the microscope, examine a slide showing fission in Paramecium. Make sketches of different stages in the process.

4. With the aid of a microscope, observe the behavior of living Paramecia. Note the swimming movements, and the response when the cell comes in contact with some object in the water. Observe the functioning of the contractile vacuoles. Place a small amount of dry carmine (stain) in the drop of culture, and observe how the cilia wash carmine particles into the oral groove. Note what becomes of the carmine particles. Prepare a report based upon your observations.
5. Obtain a bit of bark that is covered with Pleurococcus. Scrape some of the green film onto a slide, add a drop of water, cover with a cover-glass, and examine the result with the aid of the microscope. (Compare what you see with Figure 64 in the text.) Sketch several groups of cells.
6. Examine some filaments of Spirogyra with the aid of a microscope. Either permanent mounts or fresh material may be used. Identify structures with the aid of Figure 65 in the text. Sketch what you have seen, and label the various parts.
7. If some fresh or preserved Fucus is available, examine the material, and identify the structures described on page 119.
8. With the aid of the microscope, examine a slide bearing Volvox colonies. Note the cells and their flagella, and the spherical areas representing reproductive cells.
9. With the aid of the microscope, examine and sketch several types of bacteria (use permanent mounts, preferably including cocci, bacilli, and spirilla.)
10. With the aid of the microscope, examine and sketch some budding yeast cells.
11. Moisten some bread and let it stand in a loosely covered jar for several days. Examine the mold formed, with and without the aid of a microscope.
12. After consulting the reading references at the end of this chapter, construct a wall chart comparing structures of the four classes of protozoa.

SUMMARY OF PRINCIPLES

1. Paramecium is an animal that is specialized in one-celled structure.
2. Algæ contain chlorophyll and are able to manufacture food.
3. Some algæ develop colonial growths.
4. Some algæ develop special adaptations for locomotion.
5. Some algæ develop adaptations for attachment or for floating on the water.
6. Special cells which function in reproduction are found in the cases of some algæ.

7. Volvox is a colonial organism which exhibits a beginning of division of labor among cells.
8. Fungi are colorless plants; they usually are parasitic or saprophytic.
9. Bacteria are very small, colorless plants; some of them are useful to man, others are injurious.
10. Yeasts cause fermentation (so do some bacteria).
11. Lower organisms exhibit a variety of adaptations, especially in connection with obtaining food and in the process of reproduction. While they have basic similarities, they also have clearly marked differences in many cases.

GUIDE QUESTIONS

1. What is the habitat of Paramecium?
2. How does Paramecium obtain food?
3. How does Paramecium move from place to place?
4. Describe conjugation in Paramecium.
5. In what respects is Paramecium more complex than Amœba?
6. In what habitats are algæ found?
7. How does Pleurococcus obtain food?
8. What are flagella?
9. How do some algæ survive periods of unfavorable conditions?
10. Describe the rhizoid of Ulothrix.
11. What is the difference between a spore and a gamete?
12. Describe the reproductive process of Fucus.
13. Describe the structure of a Volvox colony.
14. What division of labor occurs in the case of Volvox?
15. What are the three general shapes of bacteria?
16. What is a bacterial spore?
17. How do bacteria obtain food?
18. What organisms are responsible for fermentation?
19. What is a lichen? Where do lichens grow?

BOOKS TO READ

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Mavor, J. W. *General Biology.*
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Smith, G. M., and others. *Textbook of General Botany.*
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CHAPTER VIII

THE LOWER ANIMALS

Problems:

1. Are the many-celled animals more complex than the single-celled forms?
2. In what way is "division of labor" among cells related to specialization?
3. In what ways is Planaria more specialized than Hydra?
4. In what ways is an earthworm more specialized than Planaria?
5. What adaptations of structure and behavior are shown by insects?

DIVISION OF LABOR IS ASSOCIATED WITH SPECIALIZATION

The protozoa. In previous discussions we have studied two members of the protozoan group. These were Amœba and Paramecium. We noted that they were not equally simple in structure. Even among the protozoa, we find that some species are much more complex than are other species. Taken as a group, however, the protozoa include the simplest animals — single-celled types and simple colonial species.

The metazoa. Such animals as sponges, corals, earthworms, fishes, frogs, and all higher forms, have bodies composed of many cells. These animals are classified as metazoa or multicellular types.

Cells, tissues, organs, and systems. In many metazoa, the work of carrying on various life functions is divided among different kinds of special cells. Some cells are nerve cells, some are muscle cells, some are epithelial cells, and others have special functions which have to do with various activities. A group of similar cells, such as a group of muscle cells, is called a tissue. Tissues are grouped to form organs, and organs sometimes are associated to make up systems, such as the digestive system. Thus the human digestive system consists of several organs, of which the stomach is one. The stomach includes several tissues which are composed of many cells.

Division of labor. When the work of metabolism is divided among a number of different kinds of cells we term it a "division of labor." Division of labor is correlated with specialization. The human muscle cell is specialized for purposes of contraction. It performs this one function well, but cannot perform other functions, as, for example, the work done by nerve cells. The specialized nerve cell carries nerve impulses, but it cannot do the work of contraction. The division of labor in the body of a higher organism makes for greater efficiency.

As we examine the various animal groups in turn, beginning with the Phylum Protozoa and ending with the Phylum Chordata (see pages 416–417), we find that the forms become increasingly more complex. This is another way of saying that there is increasing specialization or division of labor. It will be our purpose in this chapter and the chapter which follows to study several animals, and to observe in what ways this increase in complexity takes place.

HYDRA

(Exhibits primitive tissues)

Hydra is a simple type of metazoan. Most members of the group to which it belongs are found in the sea, but Hydra is found in fresh water. Hydra is small, but can be seen without the aid of a microscope. It usually is found attached to a stick or stem in the water. Hydra is represented by a number of species. The following description refers to Hydra fusca.

General structure. The body consists of a hollow column, closed at one end to form the basal disc, which is the usual point of attachment. (See Figure 72.) The other end of the column is surrounded by several tentacles. The mouth opening, found within the ring formed by these tentacles, is located in a slightly raised area. The body contains one large cavity which serves both as a digestive and as a circulatory chamber.

Behavior. If a living Hydra is placed in a watch glass containing water, it is possible to observe some features of its behavior. It will be noted that the animal is able to elongate and contract its body. When the animal is in the extended form it is possible to cause it to contract by touching it with a needle. Experiments in touching different parts of the body probably will indicate that the tentacles are especially sensitive.

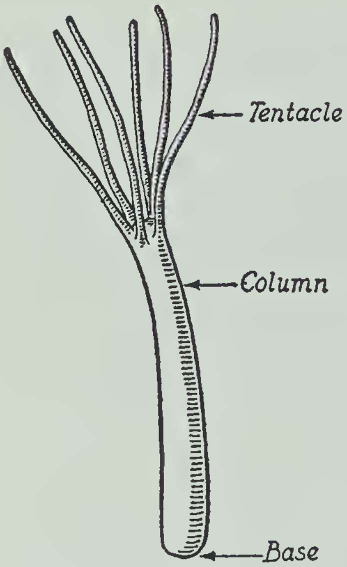


FIGURE 72. External appearance of a Hydra (diagram).

Cell layers. The body wall of Hydra is composed of two complete cell layers, the outer ectoderm and the inner endoderm. These layers are separated by a thin, noncellular supporting layer, called the mesoglœa. Division of labor and cell specialization has proceeded much further in Hydra than in Volvox.

Special cells. The outer layer contains epithelio-muscular cells in addition to some other kinds. These epithelio-muscular cells serve to form an outer covering. At the same time these cells have

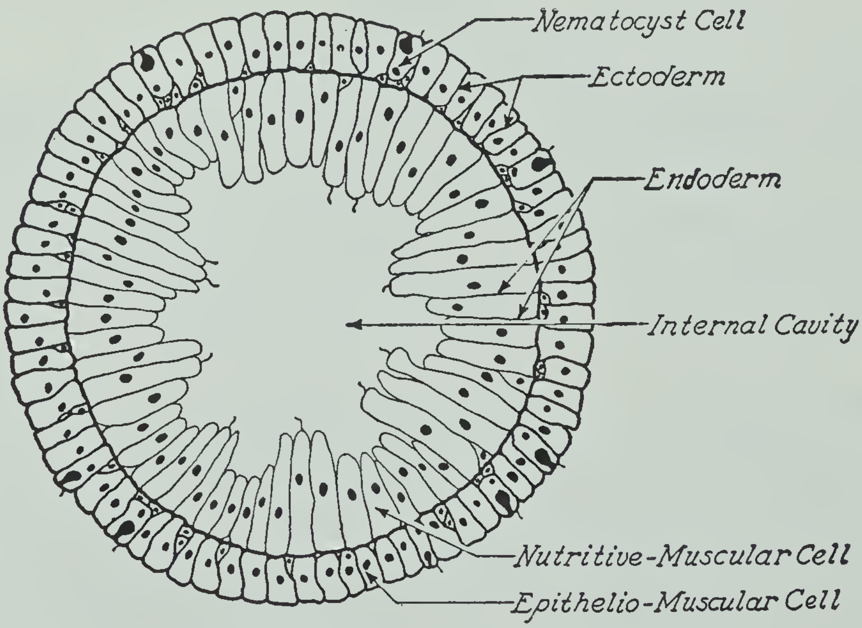


FIGURE 73. Diagram showing a cross section of a Hydra. How many cell layers has Hydra?

considerable power of contraction. Their presence accounts in part for the contractions and expansions of the column and the tentacles.

Other types of cells found in the outer layer are called nematocyst cells. These cells represent a remarkable adaptation for defense and for the capture of food. One type of nematocyst cell contains within it a poison sac, and a barbed, hollow filament. If this cell is irritated by the presence of a small animal on the outside of the body, the filament will be driven out and into the body of the victim. Then poison from the poison sac will be injected into the victim through the hollow filament. The poison serves to paralyze or kill. After a nematocyst cell has been used, it degenerates and may be replaced by a small, unspecialized cell. The latter may develop into a new nematocyst cell.

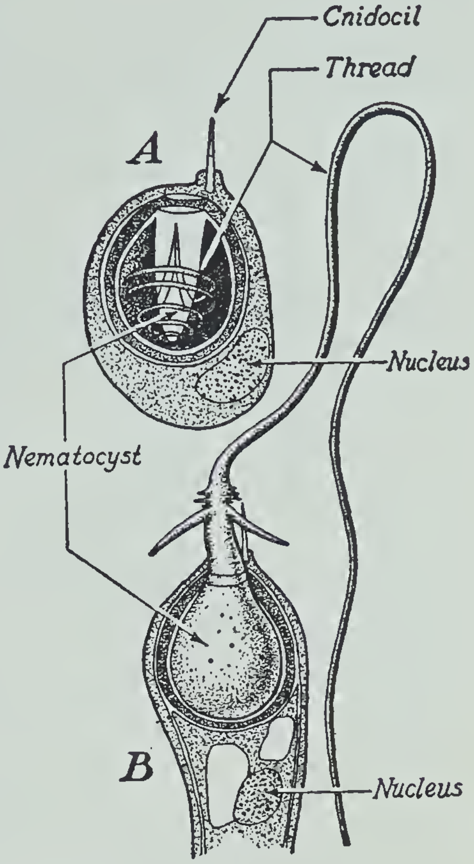


FIGURE 74. Nematocyst cells of Hydra. *A*, before discharge; *B*, after discharge. What functions do these specialized cells perform?

Other cells, found in both layers of the body wall, are considered to be primitive nerve cells. These cells form a more or less continuous "nerve set," or group of nerve cells.

The cells making up the bulk of the inner layer are called nutritive-muscular cells. They are concerned in the process of digestion, and also in contraction. They may bear flagella or develop pseudopodia. Food consists largely of small animals. These are captured by the tentacles with the aid of the nematocyst cells. The tentacles also aid in forcing food through the mouth opening and into the cavity of the body. Here some small particles of food are surrounded by pseudopodia of the nutritive-muscular cells and are absorbed. Larger bits of food are first acted upon by digestive enzymes. These enzymes are secreted into the internal cavity by the nutritive-muscular cells. The food is then absorbed by the cells.

Reproduction. At times Hydra reproduces by a process called budding. As in the accompanying figure, a bud forms as an outpushing of the body wall. The bud develops tentacles and a mouth opening. Then it separates from the parent and becomes a separate individual. More rarely a Hydra may divide to form two individuals. The division begins at the end bearing the tentacles and proceeds along the long axis of the body. This is a type of fission. Both budding and fission are asexual methods of reproduction. This means that they do not depend upon the activity of special sex cells.

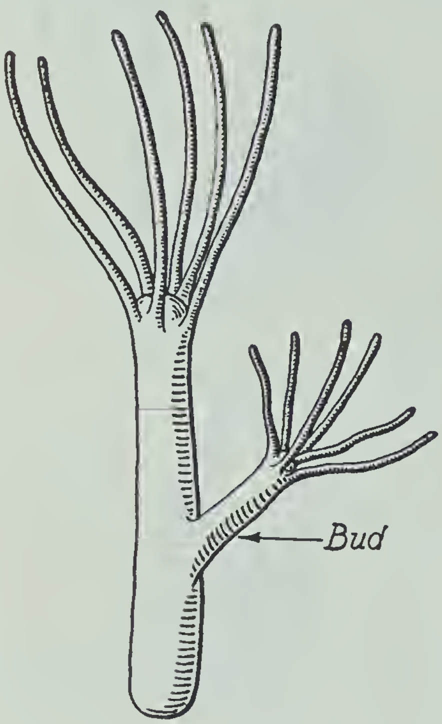
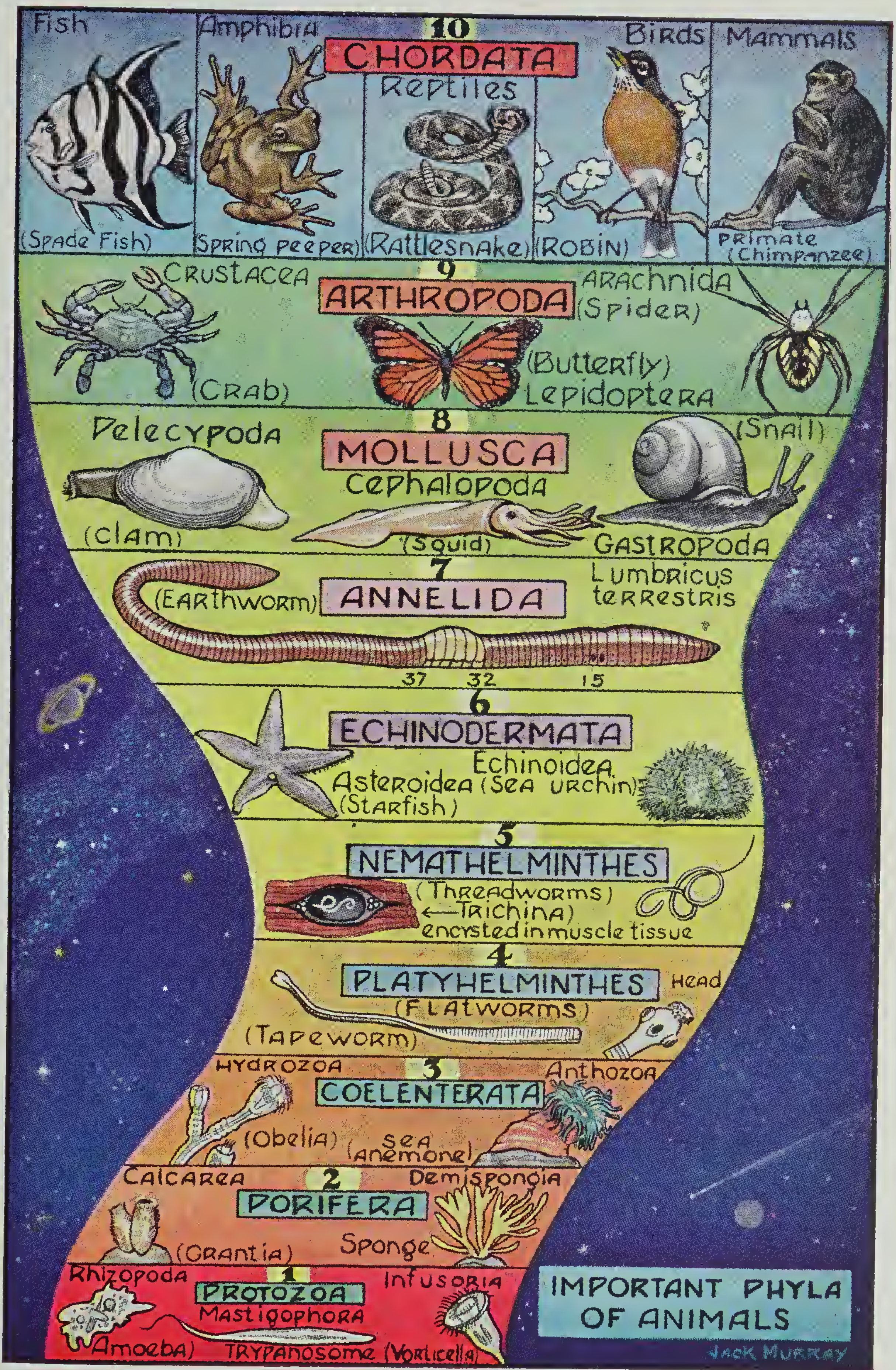


FIGURE 75. Diagram of a Hydra with a bud.

Hydra also has a sexual method of reproduction. In this case eggs (ova) and sperm are produced from certain cells of the outer layer. The ova remain in place, but the sperms break away into the surrounding water. The sperms fertilize (unite with) the ova. The latter then begin to divide and embryos are produced. At a certain stage these embryos develop protective outer coverings or cysts, and break away from the parents. After further development, the cysts dissolve and the young Hydras emerge.

Summary. Hydra shows no special developments in the way of respiratory and excretory structures. The functions of respiration and excretion are carried on separately by the cells. But there is specialization and a beginning of division of labor in the functions of reproduction, digestion and assimilation, contraction, and irritability. The groups of nerve cells, epitheliomuscular cells and nutritive-muscular cells, suggest the development of tissues.

Let us now examine a somewhat higher type of animal, and observe further specialization of structure.


IMPORTANT PHYLA OF ANIMALS

JACK MURRAY

PLANARIA

(The development of organs and systems)

General structure. Planaria[1] is a small animal classified as a flatworm, which lives in fresh water. It ordinarily is less than half an inch in length. The body is elongated and flattened. On the dorsal or upper surface two eye spots mark the head region. (See Figure 76.) These eye spots are supposed to be of value in determining different degrees of illumination. Triangular projections, called auricles, are found on either side of the head. These auricles may be of use in connection with the sense of touch. The mouth opening is located at about the middle of the lower or ventral surface. Locomotion depends in part upon the action of cilia which cover the outer surface.

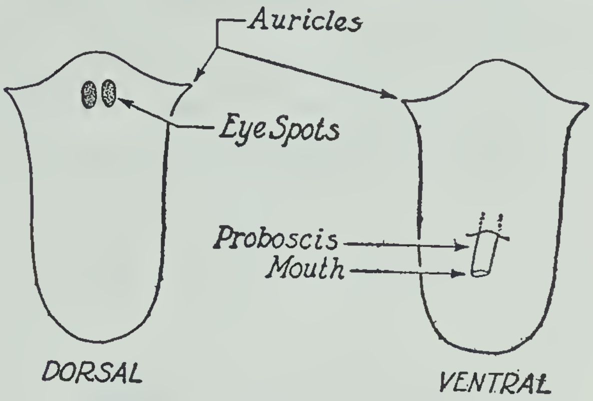


FIGURE 76. Diagram of a Planaria, showing dorsal and ventral surfaces.

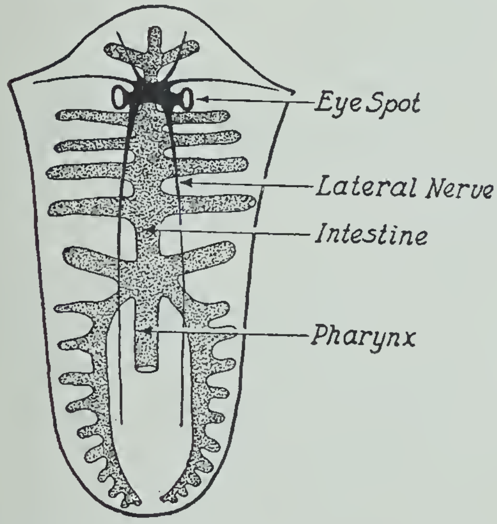


FIGURE 77. Diagram of a Planaria, showing the positions of some internal structures.

Cell layers. Planaria is placed higher in the order of classification than Hydra, and is more complex. Its body is composed of three distinct layers of cells. These are the outer ectoderm, the mesoderm, and the inner endoderm. In the case of Planaria, we may recognize tissues, organs, and systems. We no longer need confine our studies to cell structure.

Digestive system. The digestive system includes a mouth, a pharynx, and an intestine. The pharynx lies adjacent to the mouth. It may be extended out through the mouth opening in the form of a proboscis; this presumably aids in obtaining food. The intestine has three main trunks, one in the anterior part of the body and two in the posterior region. Each main trunk has many lateral branches. The result is that food materials from the digestive cavity come in contact with cells in all parts of the body. Food may be absorbed or ingested by cells lining the intestinal cavity. Solid wastes are passed out through the pharynx and mouth opening.

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[1] Planaria is a generic name. There are a number of species.

Nervous system. Planaria has a primitive nervous system. It consists of a ganglion or collection of nerve tissue in the head region, and two lateral nerve cords, one on either side of the body. Branch nerves extend to various parts of the head region.

Respiration and excretion. There is no special respiratory structure in the case of Planaria. The body being flat, all of the cells are close to the exterior and carry on an exchange of gases with the surrounding water. There is, however, a rather well-developed system for the discharge of liquid wastes. This system consists of two small tubes or tubules running the length of the body, one on either side. They open to the exterior through tiny dorsal pores. As liquid wastes excreted by body cells accumulate, they are forced into the tubules by special cells, which are located along the lengths of the tubules. The wastes then follow the tubules to the exterior.

Circulation. Because of the animal's flattened shape and the nature of its internal structure, no special system of circulatory vessels is necessary. The intestine reaches practically all of the cells and no blood vessels are needed to distribute food. We have noted that liquid wastes are collected in all regions of the body by the cells connected with excretory tubules. In higher forms of animal life the collection and removal of liquid waste is another important function in which the blood vessels take part. Finally, all of the cells are so close to the exterior that no blood vessels are needed to carry oxygen to them and carbon dioxide away from them.

Reproduction. Planaria reproduces both asexually and sexually. The asexual type of reproduction occurs by division through the short axis of the body. The two halves then become reorganized into new individuals. The power of regeneration is well-developed in Planaria; comparatively small pieces of the body, cut from the living animal, will develop into complete individuals.[1]

Planaria has both male and female sex organs in one individual. Such an animal is said to be hermaphroditic. The male sex organs are called testes, and the female sex organs are the ovaries. Egg cases or cocoons are produced, each containing from four to twenty-four fertilized eggs.

Summary. In conclusion, we should observe that Planaria develops not only organs, but also systems, such as the digestive system, the reproductory system, the nervous system, and the excretory system. Planaria also develops *three* distinct layers of cells — the ectoderm, the mesoderm, and the endoderm. All of these developments represent increase in complexity over the types previously studied.

AN EARTHWORM

(Development of the body cavity)

Earthworms in general. Earthworms are members of the Phylum Annelida. There are about eight hundred known species, found in various parts of the world, except where the soil is too cold or too dry. They vary considerably in size. Our common species are measured in inches, but other species four and five feet in length have been reported from Australia and South Africa.

We have learned that earthworm burrows may penetrate the soil to a depth of about twenty feet. Many of them wind about near the surface of the soil without any apparent reason. This may be because their construction is involved in the process of securing food. Earthworms really eat their way through the soil. They secure nourishment from the bits of organic material that are included in the soil. Some of these organic materials are digested and assimilated. The waste substances are brought to the surface of the soil and deposited as "castings" near the entrances of the burrows.

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[1] Refers to P. dorotocephala.

Earthworms of different species vary considerably in structure, although they may appear to be very similar to one who has not studied them. Study of a group of earthworms collected in any locality may reveal the presence of several different types. The following description applies to Lumbricus terrestris.

External appearance. The body is divided into a large number of distinct segments. The mouth is located on the ventral side of the first segment. A knob-like projection extends forward from the first segment, and may be used in identifying the anterior end of the worm. Each segment except the first three and the last bears four pairs of bristle-like projections called setæ. These setæ are controlled by special muscles in the body wall, and are used in locomotion. There is a thickening of the body wall on segments thirty-two to thirty-seven (varies in position in different species). This structure secretes a case in which the eggs of the animal are enclosed.

Two openings of the male sex ducts are on the ventral side of segment fifteen. Two openings of the female sex ducts are on segment fourteen. Two pairs of receptacles, which receive sperms from other individuals, open between segments nine and ten, and ten and eleven. Another pair of small openings may be found on each segment except the first three and the last. These are the external openings of structures which discharge liquid wastes. The anal opening is in the last segment.

Some of the foregoing structures are so small that they are difficult to see, even with the aid of a hand lens. Their variety and number emphasizes the fact that an earthworm is not as simple an animal as one might assume.

The body cavity. When we cut through the body of an earthworm and expose the interior structures, we are able to observe at least two distinct advances in structure in comparison with Planaria. For one thing, there is a complete digestive canal, beginning with the mouth and ending with the anus. In the second place, an earthworm has a true body cavity. It is a cavity lying between the body wall and the wall of the digestive tract. This body cavity is divided into a number of compartments by thin membranes called septa.

Digestive system. The digestive system includes a mouth, extending through segments one to three, a muscular pharynx in segments four and five, a thin-walled œsophagus in segments six to fourteen, a thin-walled crop in segments fifteen and sixteen, a thick-walled gizzard in segments seventeen and eighteen, and an intestine extending from segment nineteen to the anal opening. The pharynx is the swallowing organ. The muscular gizzard is a grinding structure. Most of the work of absorbing digested food takes place in the intestine. The wall of the intestine contains many branch blood vessels into which the absorbed food passes. There is a large fold running along the dorsal wall of the intestine. This fold adds to the internal surface area of the intestine and thereby increases the efficiency of digestion and absorption.

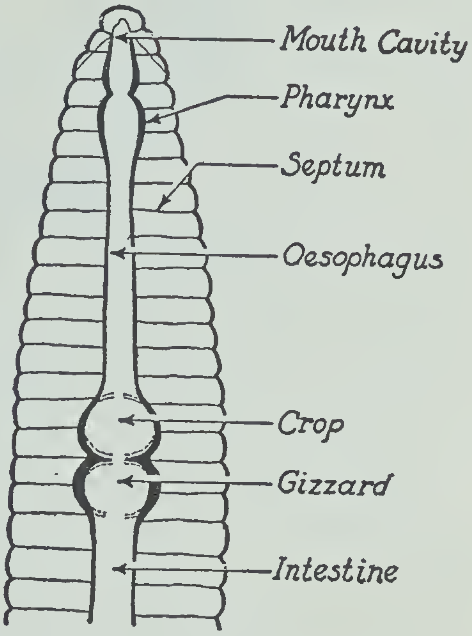

FIGURE 78. Diagram illustrating the positions of some digestive organs in an earthworm.

Blood and blood vessels. The blood consists of a basic fluid or plasma in which are a number of colorless cells called corpuscles. The blood is red because the plasma contains the red-colored substance hæmoglobin. We shall find that in such animals as frogs and man the hæmoglobin is contained in the red corpuscles. In an earthworm, however, it is the plasma that is red.

The earthworm (L. terrestris) develops a number of blood vessels of which two are noteworthy. The dorsal blood vessel is situated just above the digestive canal in the mid-line. The ventral blood vessel lies just below the digestive canal. Five pairs of "hearts"[1] connect the dorsal blood vessel with the ventral blood vessel in the region of the œsophagus. These "hearts" contract to produce a circulation of the blood.

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[1] The so-called hearts are short blood vessels that contract and thus cause a circulation of the blood.

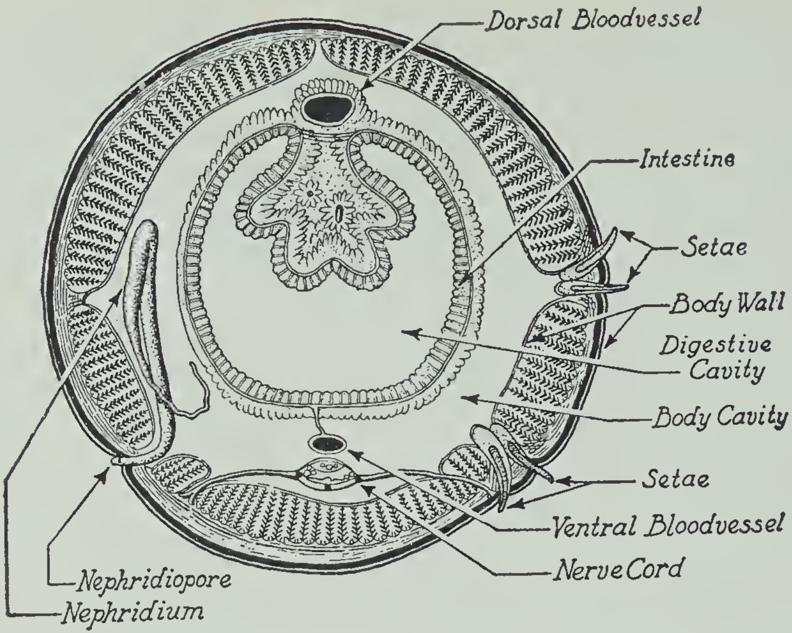

FIGURE 79. A simplified cross section of an earthworm (diagram). Compare with Figure 73. Which is "higher" in the scale of life, Hydra or an earthworm? Explain.

There also are a number of smaller blood vessels and sinuses. The latter are spaces between cells, which may be occupied by blood from time to time. They are most common among lower animals which have relatively incomplete systems of blood vessels. Branches of the circulatory system are present near the surface of the body wall. It is here that the blood receives oxygen and gives off carbon dioxide.

Nervous system. The central structures of the nervous system are a mass of nerve cells lying above the pharynx and a ventral nerve cord. The structure above the pharynx which is called a ganglion, gives off several branch nerves to the anterior end of the body. It also gives rise to two large nerves that pass on either side of the pharynx to join the ventral nerve cord. The latter structure extends backward the length of the body. It has a bilobed ganglion,[1] or thickening of nerve material, in each segment. Various branch nerves are given off by the nerve cord.

Excretion. The excretory system is represented by funnel-like structures with tubes which connect with the pores or openings to the exterior. There are two pores on each segment with

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[1] A mass of nerve cells and fibers.

the exception of the first three and the last. The open end of each funnel lies in the segment in front of the one in which the corresponding pore is located. These structures, called nephridia, collect and discharge liquid wastes.

Reproduction. The earthworm (L. terrestris) is another animal that has both male and female sex organs in one individual (hermaphroditic). Two pairs of male sex organs (testes) produce sperms. A pair of female sex organs (ovaries) produce ova. Egg cases or cocoons are secreted by cells in the region of segment thirty-two to thirty-seven. As these slip over the anterior end of an earthworm's body, they are filled with eggs and sperms.[1]

Summary. In general we see that an earthworm is more highly specialized than Planaria. Nervous, circulatory, digestive, reproductory, and excretory systems are established as specialized structures. An earthworm also develops a true body cavity, which was not found in any of the animals previously studied.

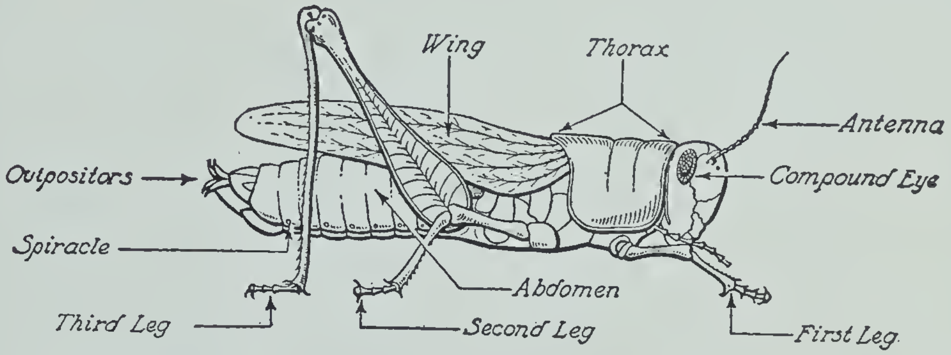

FIGURE 80. Diagram showing external structures of a grasshopper.

INSECTS

(Metamorphosis as a phase of development)

Insects belong to the Phylum Arthropoda, which ranks high among the groups of animals that do not develop backbones. Insects develop a number of special structures, some of which are not found among the members of other animal groups. A grasshopper is often studied as a representative of the insect group.

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[1] The sperms which enter an egg case are received from another individual, and retained in the receptacles until discharged into an egg case.

The skeleton. Insects do not have internal skeletons, but have well-developed external skeletons composed of chitin. Chitin is a strong, flexible, light material, well adapted to the purposes for which it is used. Some insects can withstand relatively great pressure without serious injury. Hence we may infer that the external skeleton has considerable protective value. A grasshopper may leap fifty times its own length. This fact would indicate that the external skeleton also serves successfully as a place of attachment for the muscles.

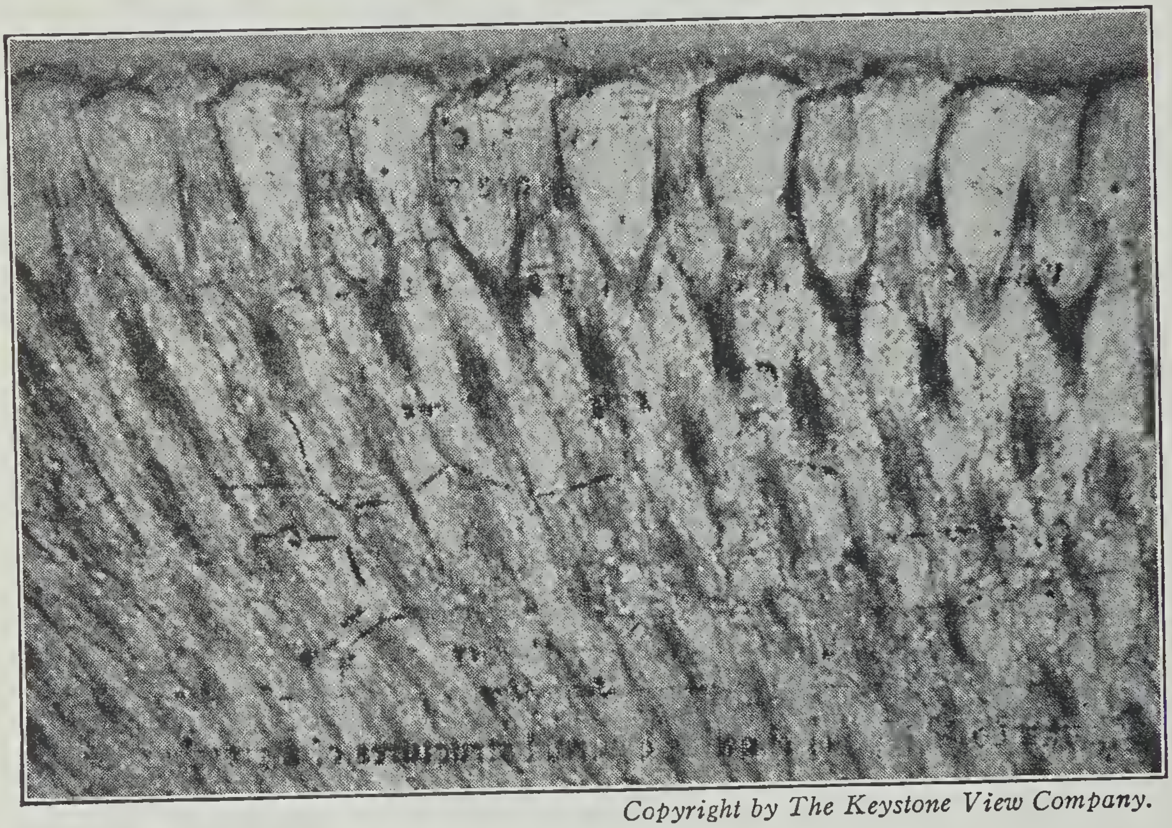

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FIGURE 81. A section of a compound eye (photomicrograph).

Segments. The insect body is divided into regions called segments. Three main divisions of the body are recognized: the head, the thorax, and the abdomen. (See Figure 80.) The head is a single segment, the thorax includes three segments, and the abdomen is composed of several segments. The antennæ, eyes, and mouth parts are located on the head. The legs and wings are attached to the thorax (wings are not present in all species). The sex organs form a part of the abdomen.

Eyes. Many insects have compound eyes in the adult stage. Each compound eye is composed of a large number of units[1] or parts. Simple eyes are also present in many cases. The simple eyes probably serve to distinguish between different degrees of illumination. The compound eyes appear to be effective in observing moving objects.

Antennæ. The antennæ are divided into a number of segments. They serve as organs of touch, and also appear to be centers for the senses of smell and hearing.

Wings. Many adult insects have wings. Some species have two wings, others have four. When four wings are present, the front pair may be heavy, and serve as covers to protect the hind pair. In such case the hind pair of wings is relied upon to furnish nearly all of the motive power of flight. There are typically six walking legs, which vary in size and structure, depending upon the habits of the species.

Digestive system. Some species of insects have mouth parts that are adapted for the purpose of chewing foods. Other species have mouth parts that are adapted for the purpose of sucking fluids. For example, grasshoppers have the chewing type of mouth parts, whereas mosquitoes have mouth parts that are used in sucking fluids. Some adult insects do not eat, and their mouth parts may be imperfectly developed.

The digestive canal of the adult insect is rather short. Adults that do not eat obtain energy from food stored during earlier stages of development. In such cases, parts of the digestive system may tend to become reduced in size (degenerate) during adult life.

Circulation. The circulatory system consists of a primitive heart lying in the region of the abdomen, a blood vessel which extends forward to the head, and sinuses.

Nervous system. The nervous system is similar to that of an earthworm. The main structures are a series of ganglia; one in the lower part of each segment. These ganglia are connected to form a ventral nerve chain. A large ganglion in the head region connects with the ventral chain by means of a pair of nerves.

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[1] Known as ommatidia.

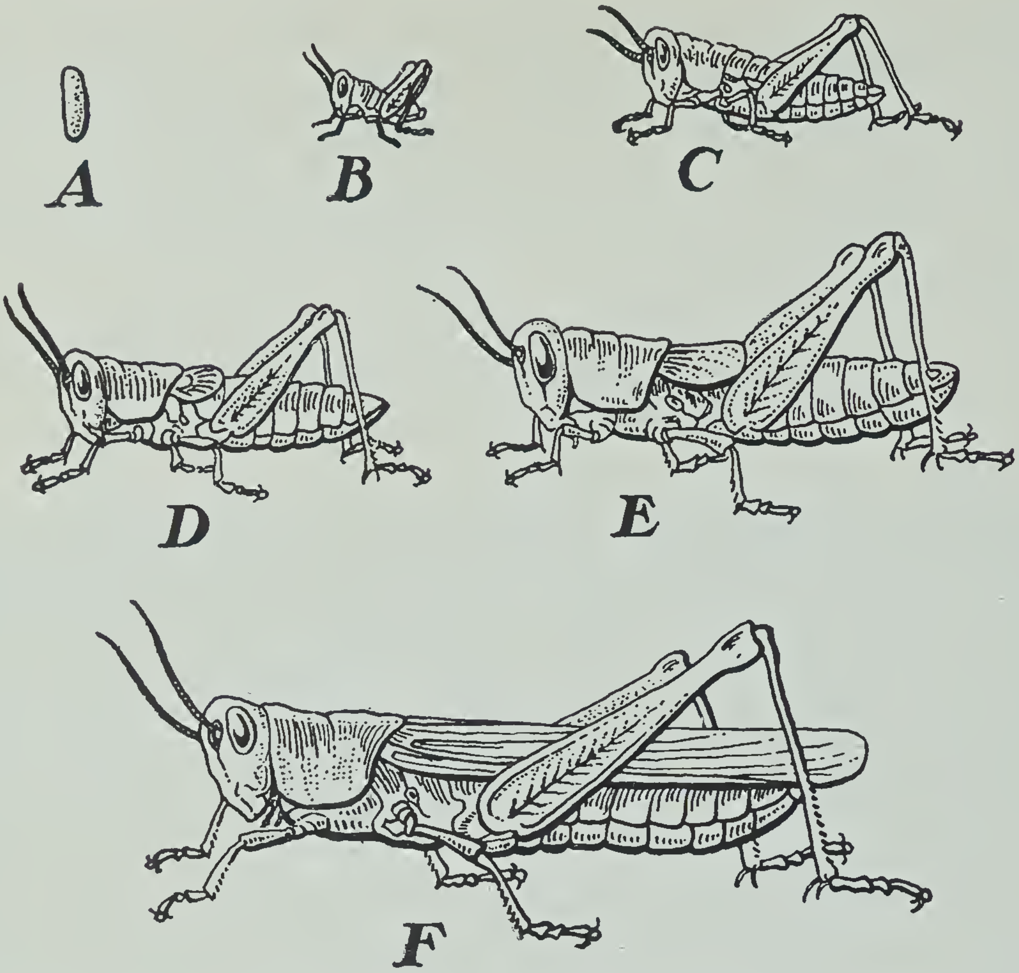

FIGURE 82. Diagram illustrating development of a grasshopper — a case of incomplete metamorphosis.

Respiration. The respiratory system of an insect exhibits some interesting structures. Insects breathe through internal tubes known as tracheæ. Air enters and leaves the tracheæ through holes located on the sides or ventral surface of the body and known as spiracles. The tracheæ branch and rebranch to all parts of the body.

Reproduction. The reproductory structures are found at the posterior end of the body. They vary according to sex and to species. The females of some species develop ovipositors; structures capable of penetrating the ground or the bark of trees. Ovipositors are used in the process of laying eggs.

The number, shape, and size of eggs varies greatly in different species of insects. Ordinarily the eggs are laid near a source of food supply for the young. Eggs may be laid singly or in "egg masses."

Metamorphosis. The life cycle of an insect such as a butterfly or a mosquito presents four stages. These are the egg, the larva which hatches from the egg, the pupa which develops from the larva, and finally the adult. When these four stages are well marked, it is said that the insect passes through "complete" metamorphosis. Complete metamorphosis is typical of the "higher" insects. In the case of a grasshopper, metamorphosis is said to be "incomplete." This is because the young grows and develops into an adult through a series of less well-marked stages — the periods of development corresponding to larva and pupa are not sharply distinguished.

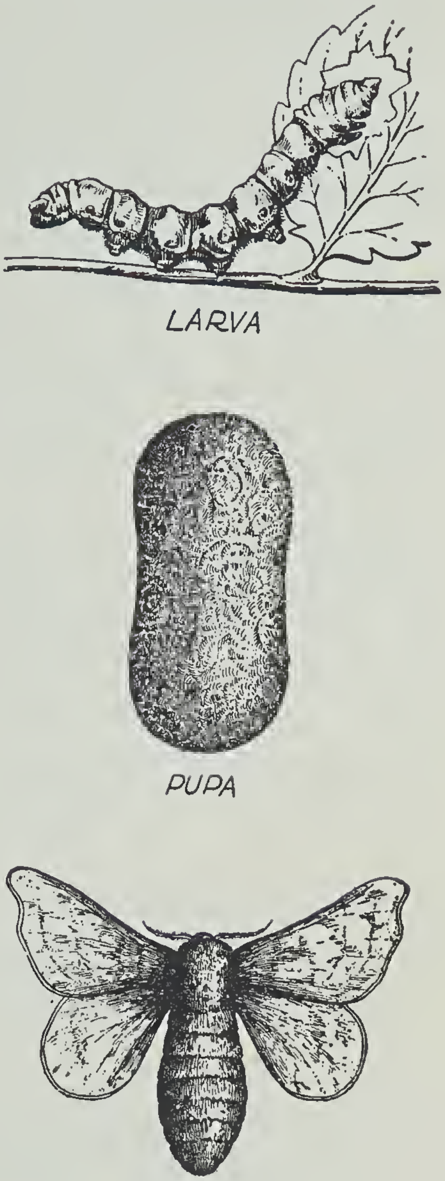

FIGURE 83. Diagram illustrating development of a silkworm — a case of complete metamorphosis. What are the four stages in this type of life cycle?

When the larvæ hatch from the eggs their activities include feeding, growing, and storing of food materials. In cases of complete metamorphosis most larvæ are worm-like in form. They are commonly known by such names as caterpillars, maggots, grubs, and wrigglers. In cases of complete metamorphosis the larvæ do not resemble the adults. In cases of incomplete metamorphosis the larvæ are similar to the adults but lack wings, compound eyes, and sex organs in most cases.

The pupal stage is one of rest and change. Among higher insects the pupa is enclosed in a pupal case. In cases of incomplete metamorphosis the form corresponding to a pupa may be active and move about in search of food.

The adult stage usually is marked by the development of compound eyes, wings, and sex organs. The main function of this stage is reproduction. In some species the adult stage lasts only a few hours, but in other species it may continue for months.

Summary. In this chapter we have discussed several of the metazoa, or many-celled animals. We have observed the formation of primitive tissues in the case of Hydra, the development of organs and systems in Planaria, and the presence of a true body cavity in earthworms. We note that an increase in complexity takes place as we study successively higher animals. The increase in complexity is associated with the division of labor which takes place among the cells of an organism. This is another way of saying that division of labor is associated with specialization.

Such animals as Hydra, Planaria, earthworms, and insects do not possess backbones. For this reason, they are called invertebrates. In the following chapter we shall see that some of the higher animals possess backbones or vertebral columns. Animals which possess backbones are called vertebrates.

SUGGESTED ACTIVITIES

Scientific methods

A scientist studies facts in order to learn general principles which may apply in other situations.

1. Examine a Hydra (living or preserved) and observe the external structure, including the base, the body column, the tentacles, and the mouth opening. If living Hydras are available observe expansion and contractions of the body columns and the tentacles. Determine whether or not the animal responds to touch stimulation by performing the experiment suggested on page 132.
2. With the aid of the microscope, examine a cross section of Hydra. (Compare what you see with Figure 73.) Identify, describe, and note the functions of special types of cells.
3. Using living or preserved Planarias, identify the external structures as described on page 135. (See Figure 76.)
4. With the aid of a microscope or microprojector, examine a cross section of Planaria. Identify cells which represent ectoderm, mesoderm, and endoderm. Note the absence of a true body cavity (cœlom). Prepare a diagram of what you have seen.

5. Using a preserved earthworm, examine and describe its external appearance, identifying as many of the structures described on page 138 as possible.
6. With the aid of a microscope or microprojector, examine a cross section of an earthworm. (Compare what you see with Figure 79.) Identify the body wall, dorsal and ventral blood vessels, the intestine, the body cavity (cœlom), and the ventral nerve cord.
7. Examine the external structure of a grasshopper, and compare what you see with the external structure of the insect as described on pages 141 to 143.
8. If mounted exhibits showing life histories of insects are available, compare a case of incomplete metamorphosis (e.g., a grasshopper), with a case of complete metamorphosis (e.g., a moth).
9. A crayfish and a grasshopper belong to the same phylum. Obtain a specimen of a crayfish, and compare its external structure with that of a grasshopper.
10. Write an explanation of the statement, "there is a well-marked change in specialization of structure in the successive types represented by Hydra, Planaria, and an earthworm.

SUMMARY OF PRINCIPLES

1. The metazoa are many-celled animals.
2. Division of labor among cells is accompanied by specialization of function.
3. The body of a complex organism contains specialized cells which may be grouped to form tissues, organs, and systems.
4. Hydra has two complete cell layers, an outer ectoderm and an inner endoderm.
5. Hydra develops a number of specialized cells which suggest the organization of tissues.
6. In Planaria, tissues, organs, and even systems are developed.
7. In addition to the ectoderm and endoderm, Planaria develops a third primary layer of cells — the mesoderm.
8. An earthworm illustrates the development of the true body cavity.
9. In an earthworm the various systems are more highly developed than in the case of Planaria.
10. Insects exhibit remarkable development of the external skeleton.
11. All insects are segmented, and develop tracheæ and six thoracic legs.
12. Many insects have wings and compound eyes.
13. Insects pass through metamorphosis in their development, which may be "complete" or "incomplete."

GUIDE QUESTIONS

1. Distinguish between protozoa and metazoa.
2. What is meant by the terms "tissue," "organ," and "system"?
3. Name three types of cells found in Hydra. State the function or functions of each kind.
4. State one or two reasons for placing Planaria higher in the scale of life than Hydra.
5. Indicate two advances in structure exhibited by an earthworm in comparison with Planaria.
6. Draw a sketch of the external appearance of a grasshopper. Indicate by names the three body regions, the appendages, and the principal sense organs.
7. What is meant by "complete" and "incomplete" metamorphosis?
8. What are the adaptations of an insect for (*a*) locomotion, (*b*) food-getting, (*c*) sensation, (*d*) respiration, and (*e*) reproduction?
9. What distinguishes a vertebrate from an invertebrate? Give an example of each type.

BOOKS TO READ

Comstock, J. H., Comstock, A. B., and Herrick, G. W. *A Manual for the Study of Insects.*
Hegner, R. W. *College Zoology.*
Mavor, J. W. *General Biology.*
Newman, H. H. *Outlines of General Zoology.*
Plunkett, C. R. *Outlines of Modern Biology.*
Woodruff, L. L. *Foundations of Biology.*

CHAPTER IX

THE HIGHER ANIMALS

Problems:

1. What differences distinguish each of the following from one another: an invertebrate, a chordate, and a vertebrate?
2. What structures are developed by all chordates?
3. What are the structural features of a vertebrate such as the frog?

Foreword. The invertebrates[1] described in the preceding chapter served to illustrate the beginnings of division of labor and the formation of tissues, organs, and systems. In this chapter we shall continue this study of increasing specialization with special reference to higher animals.

The chordates. The metazoa or many-celled animals are divided into a number of groups called phyla. The highest of these groups is the Phylum Chordata, including the vertebrates. At some stage of its life cycle a chordate develops a rod-like skeletal support or axis called a notochord. In most species, this notochord is replaced by a backbone or vertebral column. Such a species is called a vertebrate. It should be noted, however, that not all chordates develop backbones, and so not all chordates are vertebrates, although all vertebrates are chordates.

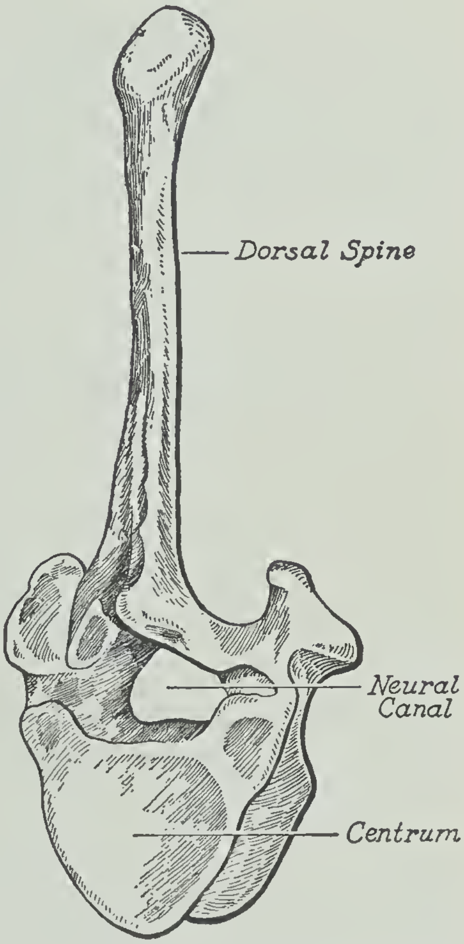

FIGURE 84. A vertebra from the backbone of a vertebrate.

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[1] Do not develop backbones.

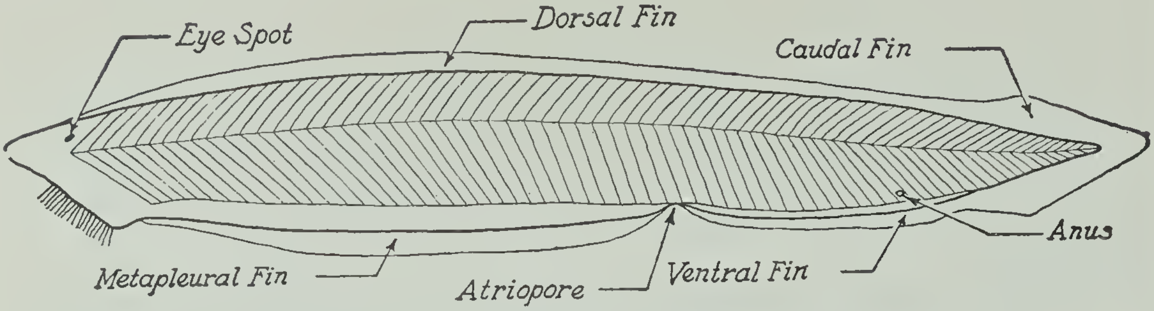

FIGURE 85. External appearance of an amphioxus.

AMPHIOXUS

(A chordate)

The amphioxus[1] (also known as the lancelet), is a small marine animal, which frequently is used to illustrate the development of the characteristic chordate structures.

The amphioxus lives along the shore of the ocean. It generally burrows in the sand, burying all of its body except the head region. It may leave its burrow at night and swim about in the shallow water.

Structures of amphioxus. The amphioxus is about two inches in length. Its body is flattened from side to side, and more or less pointed at the ends. The muscles of the body wall are divided into V-shaped segments. These segments and the twenty-six pairs of reproductory organs may be seen from the exterior. An amphioxus is either a male or a female, but the two sexes look alike. The animal possesses several fins, an eye spot, and a mouth, as will be seen in the accompanying diagram.

Three internal structures of the amphioxus are of interest in this discussion. These are the notochord, the nerve cord, and the gill slits. They can best be studied by examining a prepared slide which bears a cross section through the pharynx. As will be seen in the accompanying diagram, the wall of the pharynx is pierced by many gill slits. The gills are on the supporting walls of these gill slits. Water enters the pharynx, passes through the gill slits, and then to the exterior by way of a special cavity and pore.

[1] Refers to the species Branchiostoma lanceolatus.

The notochord extends along the dorsal mid-line of the body. It is a rod-like, supporting structure. The nerve cord lies just above the notochord. It has a continuous internal cavity. The nerve cord is the central control of this animal's nervous system.

The amphioxus has a true body cavity. In this cavity are located some ninety pairs of nephridia, which discharge liquid wastes. A number of blood vessels are present, but there is no heart. A circulation is produced by contraction of one of the blood vessels.

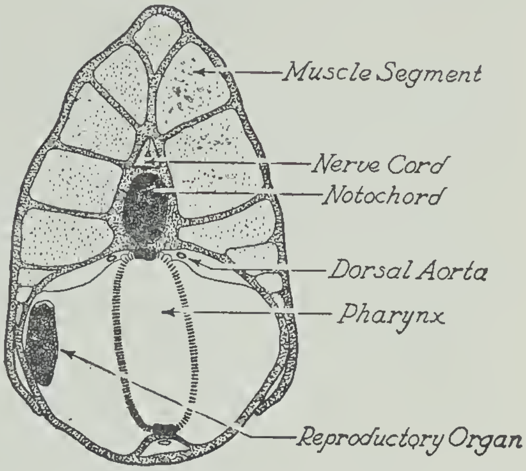

FIGURE 86. A simplified cross section of an amphioxus (diagram). Why is this animal called a chordate, but not a vertebrate?

Chordates. The amphioxus is a typical, although a simple, chordate. It possesses the three structures which are common to all chordates. These are (1) a dorsally placed, hollow nervous system, (2) gill slits, and (3) a notochord. The amphioxus is not a vertebrate, however, because its notochord does not become replaced by a backbone in adult life. Of the three structures mentioned above, only the nervous system is retained throughout the life of a higher chordate such as the bird, the dog, or man. In the latter types the nervous system becomes much more specialized. Gill slits and the notochord are developed by the bird, the dog, and man, but appear at a very early stage of the life cycle. They are not in evidence at birth or hatching. Before this time, the gill slits have become closed, and the notochord has been replaced by a backbone.

The amphioxus is an interesting type because it retains gill slits and the notochord throughout its adult life. The development of such structures indicates an increase in complexity over the animal types studied in the preceding chapter.

A FROG

(A vertebrate)

Foreword. Having studied a simple chordate, the amphioxus, we shall wish to examine the structures of a more complex chordate — an animal that is not only a chordate, but a vertebrate as well. Such an animal is a frog, which is a member of the class of vertebrates known as amphibians.

Amphibians are cold-blooded animals and they have three-chambered hearts. They may readily be distinguished from reptiles, because amphibians *do not* have external scales or plates.

Habitat. From previous discussions we have learned that a frog is found in or about water, and that marshes, swamps, or fresh-water ponds are favorite habitats. We have noted that a large portion of a frog's life may be spent in the tadpole stage, which is confined to the water.

Species. Several species of frogs are found in different parts of the United States. The leopard frog, the pickerel frog, and the green frog are species of moderate size. The bullfrog is a larger species. The following description will refer particularly to the leopard frog.[1]

Body regions. If we examine the external structure of a frog, we find that the body may be divided into three general regions for purposes of study. These are the head, the trunk, and the limbs.

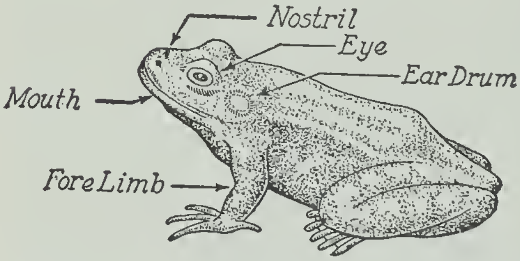

FIGURE 87. External structures of a frog.

The head. In studying the external structure of the head we may observe the nostrils, the eyes, the eardrums, and the mouth. (See Figure 87.) The two nostrils are located at the anterior end of the body. The eyes are rather large and sink down into their sockets when they are closed. Each eye has three eyelids: an upper eyelid, a lower eyelid, and a third eyelid[2] which is thin and semitransparent. This third eyelid is useful in protecting the eye from bright light.

The eardrums are located below and behind the eyes. A frog has no external ear, but the more important middle and inner portions of the ear are represented. The mouth is large, and extends almost "from ear to ear." Since the frog[1] subsists to a large extent by catching and eating insects, this large mouth is a highly desirable structural adaptation.

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[1] Rana pipiens.

[2] This third eyelid is called a nictitating membrane.

The trunk and limbs. The trunk or body proper is marked by an elevation in the mid-region of the back which is due to the presence of certain bones within the body. The anal opening, which is the posterior opening of the digestive canal, is located at the posterior end of the body. The fore limbs are relatively small. Each fore limb consists of an upper arm, a forearm, and a hand. The hand bears four digits or fingers. The hind limbs are relatively large and are the principal structures used in swimming or jumping. Each hind limb consists of a thigh (next to the body), a shank, and a foot. The foot bears five digits or toes, which are connected by a web. This web is an adaptation for swimming.

The skin. In keeping with its membership in the amphibian group, a frog has no scales or plates. Its skin is rather loosely attached to the body. This skin consists of two layers: an outer epidermis, and an inner dermis. In this respect it is similar to the human skin. Two kinds of glands are located in the skin, the mucus glands and the poison glands. These are structures which produce secretions. The mucus glands are most numerous and discharge a mucus which moistens the outer surface of the skin. The poison glands secrete a fluid which has a burning taste and serves as a protection against some animals which otherwise might eat frogs.

The body cavity. A dissection of a frog ordinarily is begun by cutting through the body wall along the mid-ventral line. We find that the body wall is composed of muscle tissue to which the skin is attached loosely. When the body cavity or cœlom is exposed, we are able to identify a number of structures within. The heart is located at about the level of the fore limbs, and is surrounded by a membrane. The dark-colored liver, divided into three lobes, lies on either side of and behind the heart. The lungs may be found near the dorsal, anterior end of the body cavity. The digestive canal is coiled within the body cavity. The kidneys are closely applied to the dorsal side of the body cavity on either side of the mid-line. If the specimen

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[1] "The" frog, as here used, refers to the leopard frog.

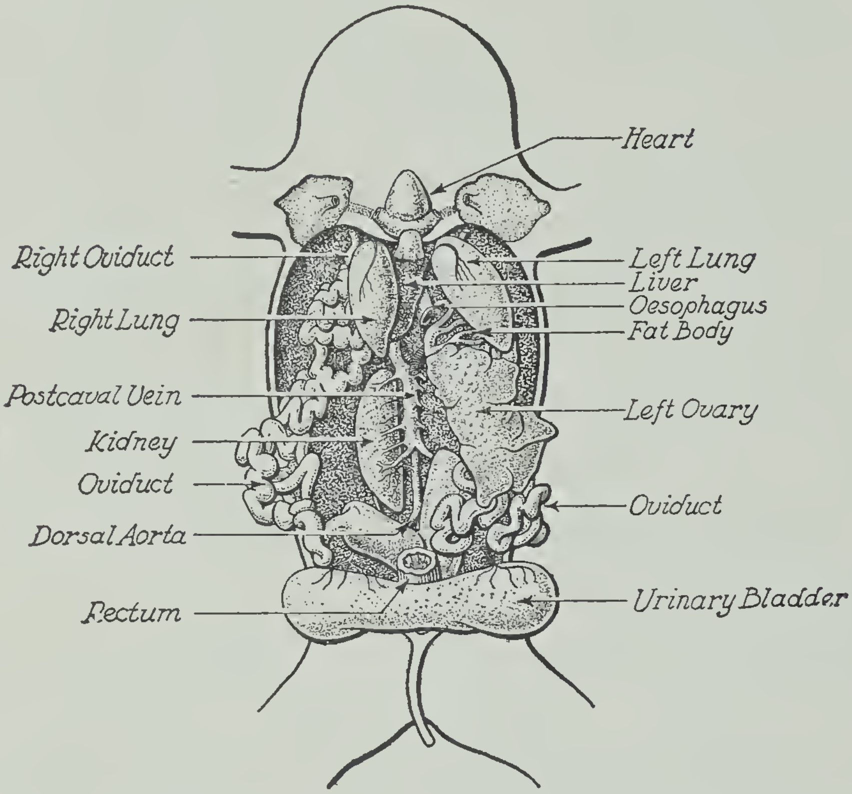


FIGURE 88. Internal organs of a female frog. Some of the organs are not shown, and the position of the heart has been changed.

is a female, the ovaries may be very prominent because of the presence of eggs in them. The female also develops two prominent, coiled oviducts, one on either side of the body.

Digestive system. The digestive system of a frog consists of a digestive canal and attached glands.

The mouth cavity is the first region of the digestive canal. The back part of the mouth cavity is called the pharynx. The tongue covers most of the floor of the mouth. It is an interesting structure because it represents a special adaptation for the purpose of capturing living insects, which, together with worms, make up the chief food of the frog. This tongue is attached, *at its anterior end*, to the floor of the mouth cavity. Its posterior end is free and partially divided or forked. The tongue is covered with a sticky secretion which aids in capturing prey. The accompanying diagram (Figure 89) will illustrate how the tongue is used.

Some short, pointed teeth are located on the upper jaw and on two of the bones supporting the roof of the mouth cavity. The two internal openings of the nostrils are also located on the dorsal surface of the mouth cavity.

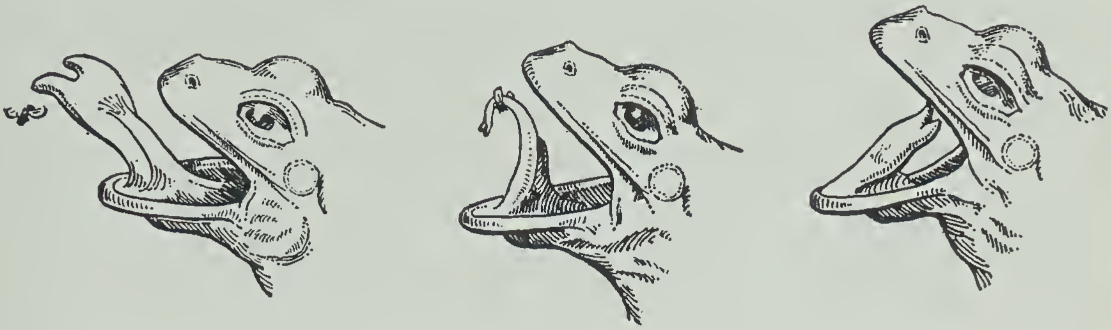


FIGURE 89. How a frog's tongue is used in capturing insects.

The glottis is a slitlike opening in the floor of the pharynx, just behind the tongue. It is the opening through which air passes on its way to and from the lungs. Behind the glottis is another opening through which food passes into the œsophagus.

The œsophagus is a short tube which conveys food to the stomach. The stomach is a saclike organ, largely lying on the left side of the body. In the case of the frog, digestion begins in the stomach. Glands in the walls of this organ secrete the enzyme pepsin which acts upon proteins.

From the stomach, food passes into the intestine. The latter structure includes a duodenum, an ileum, and a large intestine. The duodenum and ileum together make up the small intestine. The duodenum is a short, curved portion of the small intestine, extending toward the liver. It is followed by the much longer, coiled ileum. The ileum discharges into the wide, short, large intestine and the latter structure leads to the anal opening. The stomach and the three regions of the intestine are attached to the dorsal body wall by thin membranes.

The liver secretes a fluid known as bile. This fluid is collected in a saclike structure known as the gall bladder, and is carried to the duodenum by the common bile duct. The pancreas is a flattened, irregularly shaped gland, between the duodenum and the stomach. Its secretion, called pancreatic juice, is discharged into the duodenum by way of the common bile duct, which passes through a portion of the pancreas.

Digestion and absorption. Most of the chemical activity of digestion occurs within the small intestine. Glands in the wall of the intestine secrete a fluid which may have value in the digestion of carbohydrates. The pancreatic juice secreted by the pancreas contains three enzymes. One is concerned with the digestion of proteins, another with the digestion of fats, and the third with the digestion of carbohydrates.

There is some absorption of digested food by blood vessels in the wall of the stomach, but most of the absorbed food enters the blood stream through blood vessels in the wall of the intestine.

We may note that a frog's digestive system exhibits a number of specialized structures. The tongue is used as an aid in obtaining food. The digestive canal has become specialized to the extent that it is now possible to recognize definite regions, such as the pharynx, the œsophagus, the stomach, and three parts of the intestine.

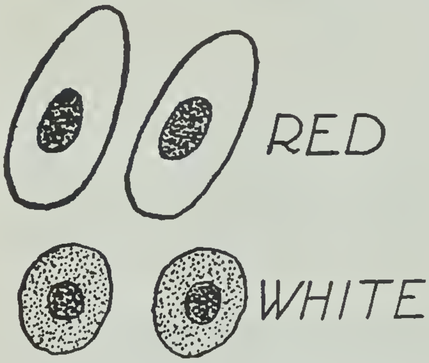


FIGURE 90. Red and white corpuscles from frog's blood. For what function are these cells specialized?

Circulatory system. Frog's blood consists of a basic plasma containing red corpuscles, white corpuscles, and spindle cells. The red corpuscles are elliptical in outline, and have nuclei. It would, therefore, be easy to distinguish them from the red corpuscles of human blood, because the latter are discoidal in shape and do not have nuclei when mature. The red corpuscles contain hæmoglobin and are the oxygen carriers of the blood. The white corpuscles of frog's blood resemble Amœba in that they are able to change shape. They ingest and destroy bacteria and wastes. The spindle cells develop into and replace red corpuscles, as the latter become worn out or are destroyed.

A frog's heart is a three-chambered structure, containing a right auricle, a left auricle, and a ventricle. The ventricle is partly divided into right and left halves by an incomplete partition. The right auricle receives venous blood from the general system. The left auricle receives oxygenated blood coming from the lungs and the skin. Both auricles discharge into the ventricle, oxygenated blood on the left side, venous blood on the right side. When the ventricle contracts, the venous blood is forced out into arteries leading to the lungs and the skin, and then the oxygenated blood is forced out into arteries leading to various parts of the body. Necessarily, there is some mixing of oxygenated and venous blood in the incompletely divided ventricle.

Respiratory system. An adult frog uses both its lungs and skin as respiratory membranes. The skin may be regarded as an extra respiratory structure, of special use to the organism during periods of dormancy.

Air enters the body through the nostrils, passes into the olfactory chambers, and then through the two nasal passages into the mouth cavity. The air now passes into the pharynx and through the glottis into the larynx. The larynx is a short tube whose walls are supported by cartilage. It serves as the "voice box," and contains the two vocal cords. From the larynx, the air enters the two lungs.

The lungs are thin-walled structures, with their interiors divided into many small air spaces. The walls of these air spaces contain many small blood vessels. It is here that an exchange of gases between the air and the blood takes place.

It should be kept in mind that in earlier stages of development, namely, in the tadpole stage, this animal develops gills instead of lungs. After the lungs have developed and the tadpole has become changed into an adult frog, the gills degenerate and disappear. Thus, in the course of one life cycle a frog illustrates the change from an animal that obtains oxygen from water to an animal that obtains oxygen from air.

Among the respiratory structures of a frog which represent features not found in the amphioxus are the lungs and their circulatory connections, the larynx with its vocal cords, and the arrangement by means of which air passes from the nostrils to the mouth cavity.

Nervous system. The nervous system of a frog is far more specialized than that of the amphioxus.

The brain of a frog is developed to the point at which we are able to recognize certain special regions that may be seen in the accompanying diagram (Figure 91). The so-called olfactory lobes are located at the anterior end of the brain. From them two nerves that may function in connection with a sense of smell extend forward to the walls of the nasal passages. The cerebrum, also consisting of two lobes, is well enough developed to be recognizable. Its function in the case of a frog is not definitely known. In higher vertebrates the cerebrum functions in connection with the more complex mental processes. Optic lobes are well developed in a frog. They are associated with the sense of sight. The cerebellum is represented by a bandlike area behind the optic lobes. Then follows the medulla, which is continuous with the spinal cord. The functions of the cerebellum and the medulla, likewise, have not definitely been determined in the case of frogs.

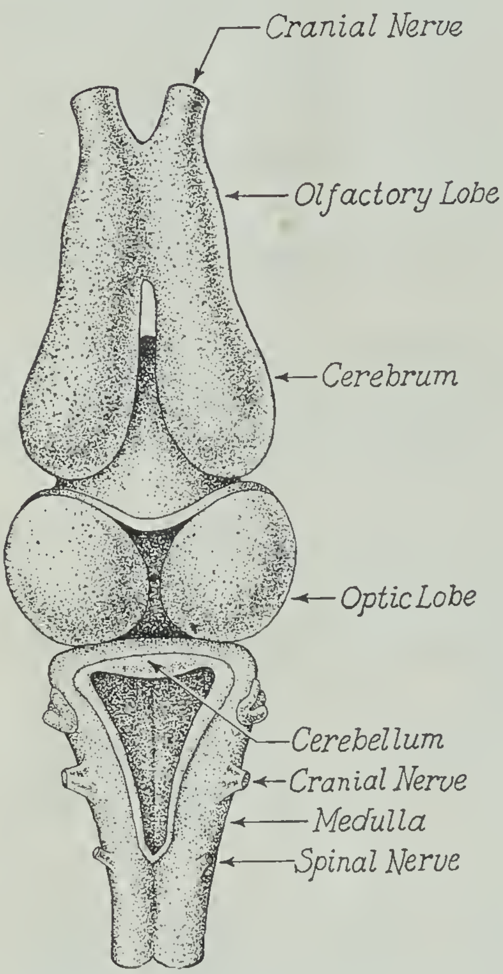


FIGURE 91. Diagram showing a dorsal view of a frog's brain. Does an earthworm have any structure which is similar to the brain of a frog?

Experimental evidence indicates that frogs have little ability to profit from experience. Most if not all of their activities may be classified as acts which are largely mechanical and not dependent upon memory.

Ten pairs of cranial nerves lead from the brain to various parts of the body. The first pair of cranial nerves, for instance, extend to the walls of the nasal passages. The second pair connect with the eyes. The eighth pair connect with the ears.

They are called cranial nerves because they arise from the brain, which lies within the part of the skull known as the cranium.

The spinal cord extends along the dorsal mid-line from the medulla to the posterior end of the body. It gives off ten pairs of spinal nerves, and these spinal nerves branch to various parts of the body.

The spinal cord contains a central cavity (neurocœle), which is continuous with the cavity of the brain. Thus we see that a frog has a dorsally located, hollow nervous system. We may recall that this is another characteristic of all chordates.

The sympathetic nervous system of a frog, which has to do with the control of certain involuntary activities, consists of two main trunks. One trunk lies on either side of the spinal cord. These trunks make unions with the ten pairs of spinal nerves. The nerves of the sympathetic system extend to the internal organs.

Special senses. As to special sense organs in a frog, the nerves in the walls of the olfactory chambers *may be* associated with the sense of smell. Similarly, nerve endings on the surface of the tongue and in the mouth cavity *may be* associated with a sense of taste. Nerve endings in the skin have to do with the sense of touch.

The eye of a frog is like that of man (see p. 319) in general structure. There is a layer called the retina — which connects with the brain by means of the optic nerve — a lens, and a pupil. The latter is the opening through which light enters the eye. Although a lens is present, there is no provision in the case of a frog's eye for focusing. In the case of the human eye, focusing is achieved by changing the shape of the lens.

Each ear of a frog consists of a middle ear and an inner ear. The eardrum (tympanic membrane) is stretched across the entrance of the middle ear. A rodlike structure (columella) extends from the eardrum to the inner ear. The inner ear is the real organ of hearing, as it receives the auditory nerve. It also serves as an organ of balance. Sound waves cause the tympanic membrane to vibrate, and the vibrations are conveyed to the inner ear by the columella. Fundamentally, this is not unlike the human ear, except that in man the external ear is present, there are three bones ("hammer," "anvil," and "stirrup") in the middle ear, and the inner ear shows greater refinement of structure.

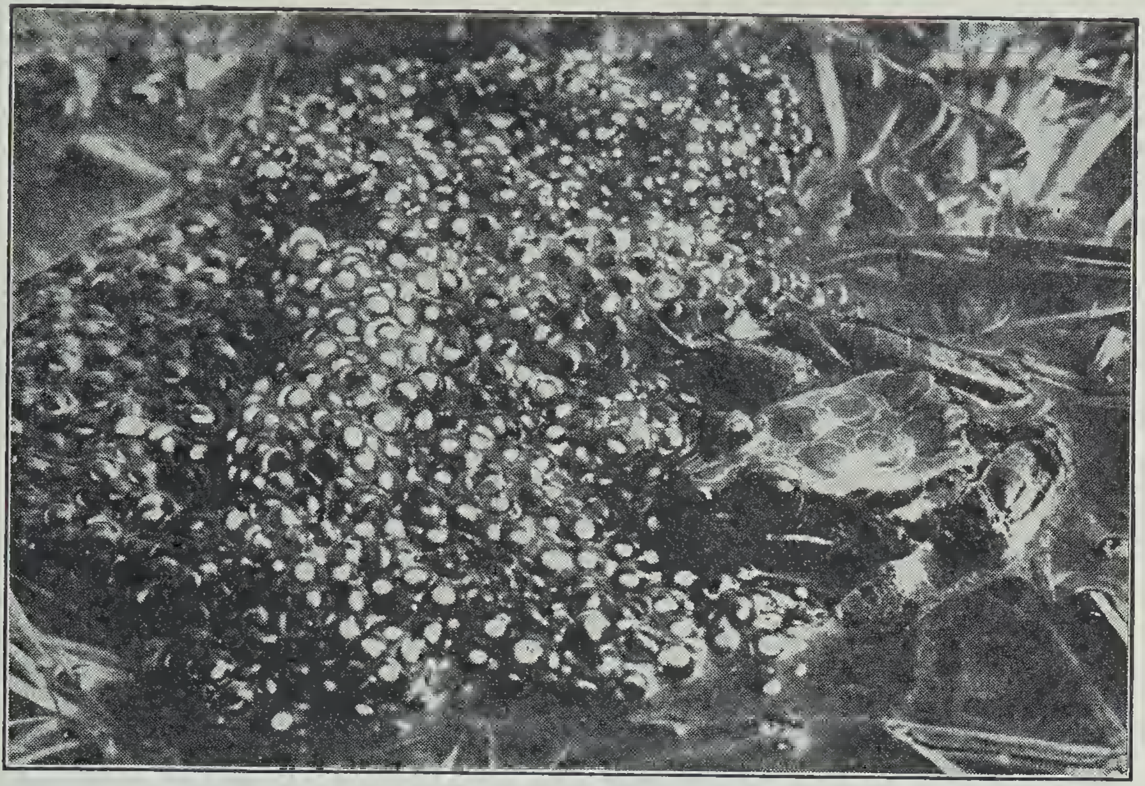
Excretory system. The location of the kidneys along the dorsal body wall has been noted. The kidneys receive blood by way of arteries and veins, and discharge blood by way of veins. Upon entering the kidneys the blood contains wastes which are the result of metabolism in the many cells of the body. The kidneys remove these wastes and discharge them through ducts. One duct from each kidney extends back to connect with a chamber called the cloaca. The liquid waste passes from the cloaca to the bladder. Here it is retained until it is discharged from the body through the anal opening. This is a rather complex excretory system when compared with the nephridia found in the amphioxus.

Reproductory system. The male sex organs include the testes: light-colored, oval bodies located in the posterior part of the body cavity near the kidneys. The sperms developed in the testes pass through ducts to the cloaca and from there to the exterior through the anal opening.

The ovaries of the female are two dark-colored masses (when filled with ova), one lying on either side of the body. The ova or eggs are small, black and white in color, and spherical. The ova must break out into the body cavity and then enter the oviducts. Strangely enough, there is no direct connection between the ovaries and the oviducts. The latter are two coiled tubes, one on either side of the body, their openings up near the anterior end of the body cavity. The ova, after having entered the oviducts, receive a gelatinous covering. Then they pass posteriorly down the oviducts to the cloaca and the exterior.

It will be noted that the reproductory organs of a frog have become specialized to the point that there is considerable difference between males and females. It will be recalled that in the case of the amphioxus there was no obvious difference between the two sexes.

Skeleton. The skeleton is of particular interest to us, because the frog is the first animal studied in this series which qualifies



Acme.

FIGURE 92. A female leopard frog and her mass of newly laid eggs.

as a vertebrate as well as a chordate. Although in earlier stages of development a frog passes through a notochord stage, the skeleton develops bony elements in later stages. Meanwhile the notochord is replaced by a bony, vertebral column or backbone. The latter is segmented to form a series of vertebræ. The central structure of each vertebra represents a transformed portion of the old notochord.

In general, although a frog has a bony skeleton, it should be noted that a considerable amount of cartilage is present.

We may divide the skeleton into several regions as follows:

1. The skull — enclosing the brain and including the upper and lower jaws.
2. The vertebral column or backbone.
3. The shoulder bones and the fore limbs.
4. The hip bones and the hind limbs.

The same general regions may be recognized in the case of the human skeleton. There are great differences, however, in the shapes of various bones, and not all of the bones found in a frog are found in the human skeleton.

Development. The eggs of the leopard frog are laid in masses in shallow water. They are fertilized by the male at the time of laying. After a period of time tadpoles may develop and break free from the egg masses. These tadpoles are very different from adult frogs in appearance. At first they are more or less fishlike in form, and breathe by means of external gills. Then four pairs of internal gills are developed and the external gills disappear. Hind limbs are now formed, and later on front limbs make their appearance. The tail begins to be absorbed back into the body proper.

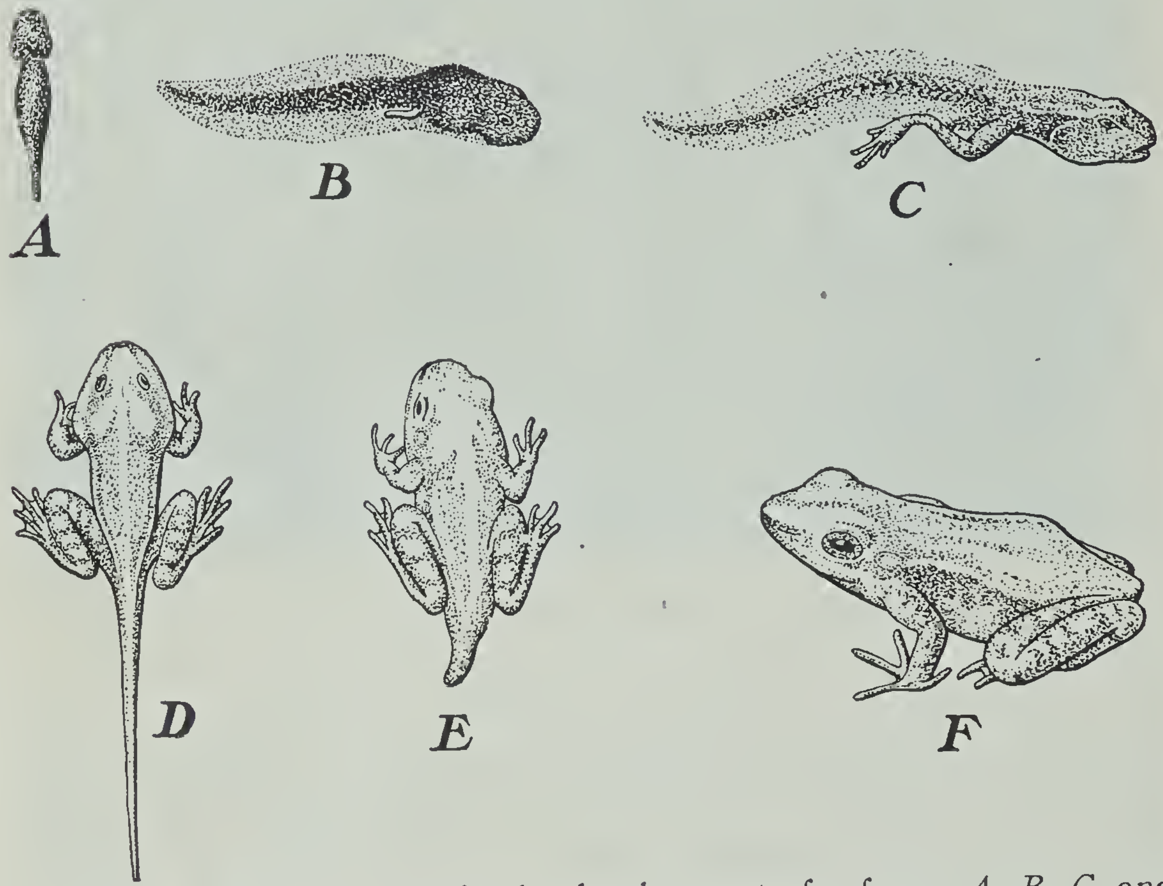


FIGURE 93. Various stages in the development of a frog. *A*, *B*, *C*, and *D* represent tadpoles; *E* is a stage in transformation; *F* is a young adult.

The tadpole is now approaching the time for changing to the adult stage. The preceding stages ordinarily occur within one season. The tadpoles of the bullfrog, however, require two or three years for their development. Ordinarily, if the tadpole is to change into an adult frog, a sloping beach must be available. In the absence of such a sloping beach the change may not take place. In the course of transformation the four pairs of internal gills disappear, and the lungs are developed.

SPECIALIZATION RESULTS IN COMPLEX STRUCTURE

In this chapter and the preceding chapter we have given our attention to increasing specialization. Beginning with comparatively simple animal forms, we have studied the development of specialized cells, then tissues, then organs, and finally systems.

We found that in the case of Paramecium a single cell performed all of the activities of life. In Volvox there was a suggestion of division of labor involving a few cells. Hydra exhibited further specialization and division of labor among cells. In the case of Planaria we found that definite tissues, organs, and systems had been developed.

In studying an earthworm, insects, the amphioxus, and a frog, we have seen that organs and systems become more complex. We have studied the transition from aquatic life (tadpole) to life as an air breather (frog). We have noted that the notochord serves as an antecedent for the backbone.

There is a vast difference in complexity and specialization between Paramecium on the one hand and a frog on the other. Yet it must be kept in mind that these two forms of life have fundamental similarities as well as differences.

Summary. In summarizing, it now should be clear to us that as the animal body becomes more complex there is an ever increasing division of labor among cells. Cells become specialized in performing certain definite functions, and at the same time lose the ability to carry on a variety of functions. Meanwhile the organism as a whole has become more complex. Thus we say that specialization results in complex structure.

SUGGESTED ACTIVITIES

Scientific methods

A scientist keeps records in an orderly way.

1. Examine a preserved specimen of the amphioxus with a hand lens. Identify the external structures described on page 150.

2. With the aid of a microscope or microprojector, examine a cross section of the amphioxus (through pharynx). (Compare what you see with Figure 86.) Identify in particular the gill slits, the notochord, and the nerve cord with its internal cavity.
3. Examine a living or preserved frog, and identify the structures described on pages 152 and 153.
4. Expose the body cavity of a preserved frog by making an incision along the ventral mid-line. Following the description of internal structure on pages 153 to 160, and with reference to Figure 88, identify as many of the internal systems as possible. Examine models of the frog's brain and nervous system. Examine a frog skeleton, and identify the structures described on page 161.
5. Examine tadpoles in various stages of development. Prepare a chart to illustrate development of the frog from the egg stage to the adult stage.
6. Discuss the differences between gills and lungs as adaptations for securing oxygen.
7. In three vertical columns, compare an insect, the amphioxus, and a frog with respect to the following: digestive system, nervous system, notochord, vertebræ, respiration, and reproduction.

SUMMARY OF PRINCIPLES

1. Chordates develop a dorsal, hollow nervous system, gill slits, and a notochord.
2. Amphioxus represents a primitive type of chordate.
3. A frog is a vertebrate and exhibits a comparatively complex development of organs and systems.
4. The Animal Kingdom, when viewed as a whole, represents a picture of increasing complexity, from the simpler animals on the one hand, to the complex or higher animals at the top of the scale.

GUIDE QUESTIONS

1. What special structures identify the amphioxus as a chordate?
2. Why is the amphioxus not a vertebrate?
3. What is meant by a "true body cavity"?
4. Compare the amphioxus and an earthworm as to their means of respiration.
5. Compare the nervous system of the amphioxus with that of a frog.
6. What functions does a skeleton serve?
7. What is the meaning of "amphibian"?

8. Describe the adaptations of the leopard frog for (*a*) life in the water, (*b*) life on land.
9. Describe the heart and blood of a frog.
10. What are three adaptations of a frog for swimming?
11. Describe the leopard frog's method of obtaining food, and the adaptations for this function.
12. Arrange the following animal types in order of increasing complexity of structure. Begin with the simplest: amphioxus, Hydra, frog, Amœba, Planaria, earthworm, Paramecium.

BOOKS TO READ

Hegner, R. W. *College Zoology.*
Newman, H. H. *Outlines of General Zoology.*
Walter, H. E. *Biology of the Vertebrates.*
Woodruff, L. L. *Foundations of Biology.*

CHAPTER X

THE STRUCTURES OF PLANTS

Problems:

1. In what ways do liverworts exhibit specialization of structure?
2. In what ways are mosses more specialized than liverworts?
3. What specialized structures are found among ferns and their allies?
4. What are the structural features of the seed plants?

THE LIVERWORTS

(Illustrating adaptations for life on land, and alternation of generations)

Foreword. In continuing study of the plant body we should recall that some species of algæ exhibit divisions of labor among cells. We also may recall that many of the algæ studied were species that lived in the water. Many of the plants that we see about us are terrestrial — they live on the land. These facts lead to a number of questions. For example: What are the main differences between land plants and aquatic plants? Are there any plants which show beginnings of adaptation for terrestrial life? Do plants, like animals, exhibit increasing complexity of structure when we examine successively "higher" types?

Riccia. When you visit the fresh-water pond in early summer you may observe some small, green, oval bodies floating on the water near the shore. Perhaps these structures resemble leaves, but have thickened areas like those of Fucus instead of veins. They also have some whitish rhizoids extending downward from their lower surfaces. If so, they probably belong to the genus Riccia. Riccia is a liverwort.

If the pond becomes shallow in late summer, you may find Riccia on the mud of the shore. Its rhizoids now extend down into the mud, where they absorb moisture and mineral compounds. Thus we see that Riccia is adapted to live in the water or upon moist soil.

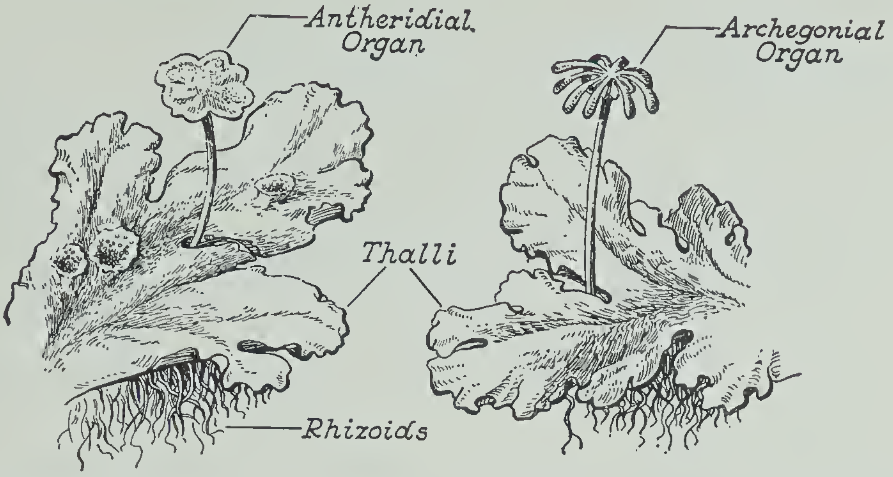


FIGURE 94. Diagram of a liverwort (Marchantia). In what ways does this plant resemble the "higher" algæ?

Marchantia. Marchantia is another liverwort which is found living upon moist soils. It has the appearance of a small, greenish leaf, which adheres closely to the surface of the ground, as is indicated in the accompanying figure. If you can obtain specimens of Marchantia you may be able to see the following features:

1. The thallus is many cells in thickness, with a protective layer of cells (epidermis) on both upper and under surfaces. This prevents rapid evaporation of water.
2. Cells with numerous chloroplastids lie beneath the upper epidermis. They manufacture food.
3. The epidermis has specially formed cells, which by contraction and expansion regulate openings from the exterior into the air spaces between the cells. These openings are called pores. They not only admit air but also affect the rate of evaporation.
4. Between the lower epidermis and the layer of food-making cells are cells which store food.
5. Certain cells of the lower epidermis form structures which extend downward. These are rhizoids, which by osmosis absorb water and mineral substances and transmit them by the same means to the other cells of the organism.

6. Little, shallow, saucerlike outgrowths scattered here and there on the upper surface produce green buds (gemmæ) which are liberated and scattered over the ground by water. New plants can develop from these buds.
7. Two kinds of stalked structures (for sexual reproduction) may be seen growing out from the ribs of the thalli. One type bears the male sex organs (antheridia). The other type bears at the top the female sex organs (archegonia.)
8. A little, oval-shaped group of cells, also with a very short stem, may be found growing on the under side of *one* of the reproductive stalks mentioned in item 7. This is a sporogonium.

Alternation of generations. Liverworts, such as Marchantia, have a method of reproduction that involves "alternation of generations." This alternation of generations also occurs in higher forms of plant life. The plant develops two body forms which appear alternately. Thus every other generation is similar in form.

In Marchantia, the thallus with its reproductive organs (antheridia and archegonia) represents one generation. The small sporogonium, developing within the old archegonium, is the alternate type or generation.

When the "egg cell" from an archegonium is fertilized by a "sperm cell" from an antheridium, a fertilized egg results. This fertilized egg does not develop into another thallus. Instead, it produces a small plant body growing like a parasite upon its parent, which in turn develops many minute spores. When these spores are scattered, each may begin to form a multicellular plant body of thallose form. Thus the thallus generation produces sex organs and gametes (eggs and sperms), and is a gametophyte — a plant bearing gametes. The sporogonium produces spores, and therefore is known as a sporophyte — a plant body which bears spores.

Liverworts in general. There are about 4000 species of liverworts. None of them is important from an economic standpoint, but as a group they have considerable biological significance. They develop such structures as thallus bodies, rhizoids, and cells containing chloroplastids. These structures

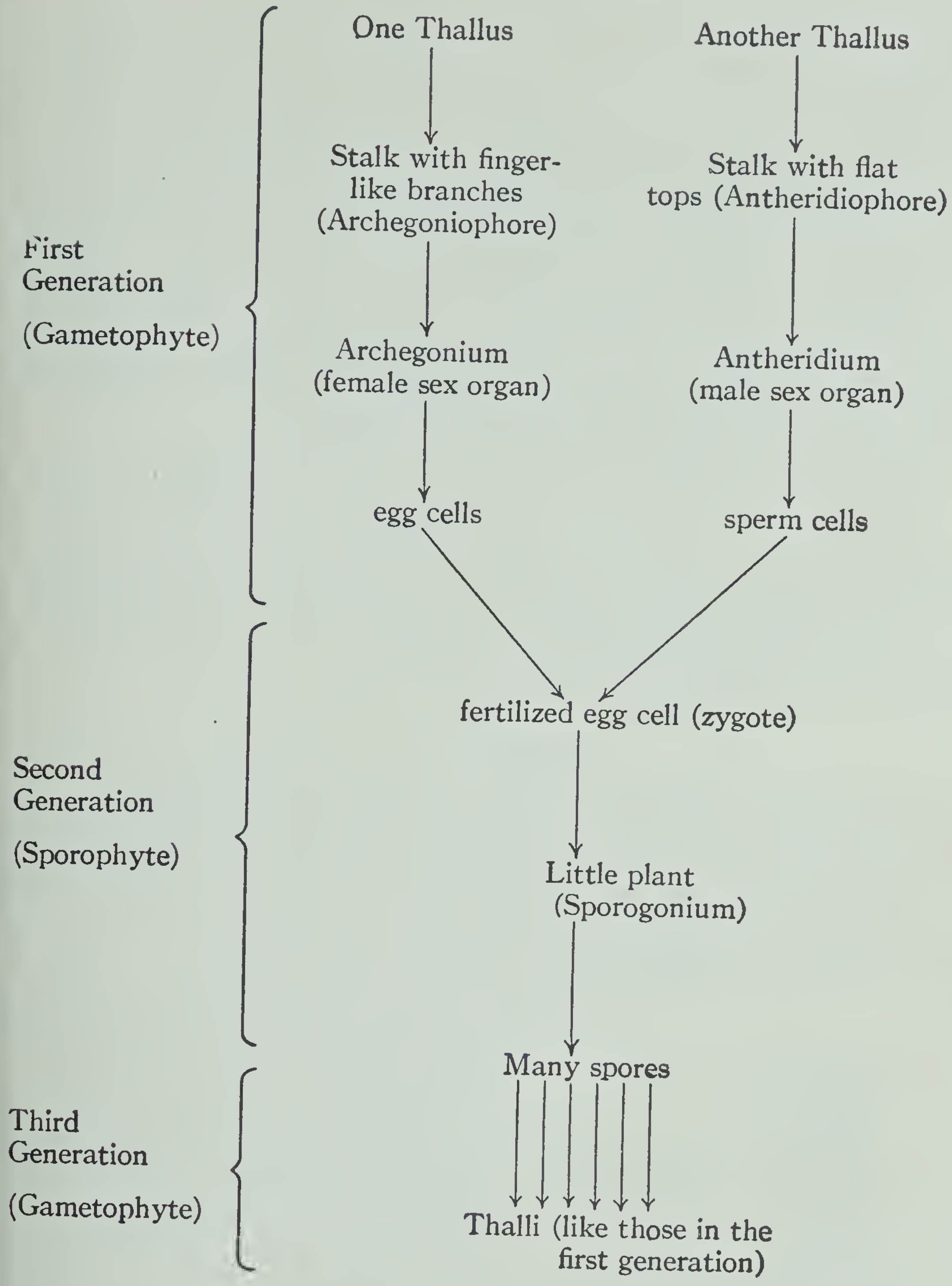

First Generation
(Gametophyte)
Second Generation
(Sporophyte)
Third Generation
(Gametophyte)
One Thallus
Another Thallus
Stalk with finger-like branches (Archegoniophore)
Stalk with flat tops (Antheridiophore)
Archegonium (female sex organ)
Antheridium (male sex organ)
egg cells
sperm cells
fertilized egg cell (zygote)
Little plant (Sporogonium)
Many spores
Thalli (like those in the first generation)

FIGURE 95. Diagrammatical explanation of reproduction in Marchantia. Read from top to bottom.

also are found among the algæ. In addition to such specialization, however, liverworts such as Riccia have adaptations which enable them to live in the water or upon a moist soil. Marchantia lives on the land, although in rather moist situations.

The fossil record indicates that in very ancient times no land plants existed. In later rocks, fossils of land plants are found. There must have been a time when some plants began to live in swampy situations upon the land. It is believed that liverworts may have been among the first plants which possessed adaptations enabling them to live upon the soil.

In conclusion, we have noted that alternation of generations occurs among the liverworts. This process continues to be a feature in the lives of higher types of plants. In Marchantia, the sporophyte is small in size. The gametophyte is comparatively large. In studying higher types of plant life we shall discover a progressive change in this situation.

MOSSES

(Illustrating increased specialization of the sporophyte generation)

Mosses, like liverworts, are members of the Division Bryophyta. (See p. 415.) Sometimes we find them growing beside liverworts in moist soils. But mosses are able to live with somewhat less moisture than is essential to the well-being of liverworts. Hence in some places we find mosses crowding out the liverworts.

Structure. Moss plants are small, without thallose bodies, but with many rhizoids. The familiar "mossy banks" are the compact masses of thousands of moss plants growing together as a result of spreading or multiplication by vegetative (asexual) methods. If you tread on moss, you get the impression of a velvety carpet beneath your feet. This is partly because the dead,

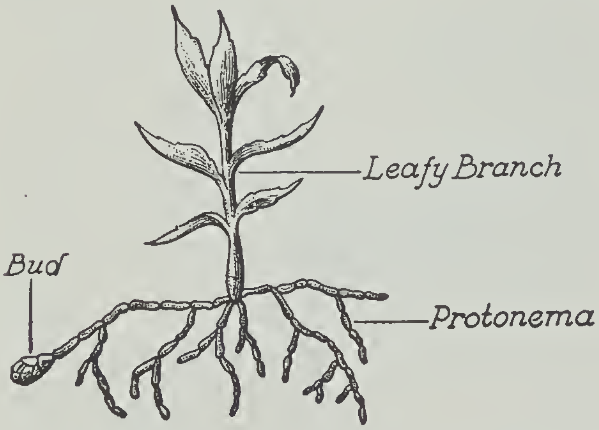


FIGURE 96. Diagram of a moss. Is the gametophyte or the sporophyte generation shown here?

tangled mass beneath continues to absorb moisture and support the living plants above. The erect portions of the moss body consist of short, but well-developed, leafy structures. These leafy structures contain chlorophyll, and are able to manufacture food. Single plants are often tiny, but as colonies mosses spread over large areas. The conspicuous part of the plant is the gametophyte. From the ground the plants absorb moisture. They spread out upon the surface by means of a threadlike growth called the protonema. From this branching mass, buds arise at intervals, and develop into new plants (vegetative reproduction).

Sexual reproduction in mosses. The sexual method of reproduction among mosses follows the same plan as is illustrated by the liverworts. There are, however, well-marked changes in the forms of certain structures, suggestive of what we find among seed and flowering plants. Antheridia and archegonia are developed by the gametophytes of mosses, at the tips of the leafy branches. In moist weather, the sperm cells from the antheridia move through films of water to fertilize the egg cells of the archegonia. Each fertilized egg cell may develop into a sporophyte. The latter is a relatively long, slender plant, more or less "parasitic" upon the gametophyte, and extending up into the air above the gametophyte.

This relation is shown by Polytrichum, a common moss whose sporophytes usually appear very early in the spring and are often called "pigeon wheat." You should note this important advance in adaptation for land life. The sporophyte has become comparatively larger than those of Riccia and Marchantia, even though it still is partially "parasitic" upon the gametophyte. In some mosses the sporophyte is green.

To what extent are mosses specialized? The mosses and the liverworts are small plants growing close to the ground. The "higher" plants, for the most part, are larger in size and also are more successful in establishing themselves upon land. This success is, of course, one reason for calling them "higher."

The possession of a sporophyte form of body which can grow up into the air to come in contact with sunlight is a structural evidence of a "higher plant." Although a sporophyte generation appears among mosses and liverworts, it does not reach its greatest development in these types. We see, also, in some mosses, that the cells of the sporophyte contain chlorophyll. Hence this generation of the plant may to some extent manufacture its own food. In higher plants the sporophyte becomes entirely independent of the gametophyte in the matter of obtaining nourishment.

FERNS AND THEIR ALLIES

(Showing further specialization with regard to nutrition, conduction, and reproduction)

We have seen that there is a tendency among the mosses to develop the sporophyte into a stalk, and for its cells to contain chlorophyll. Both of these tendencies are developed more prominently among the ferns.

Vascular systems. Among algæ, and the simplest plants which manage to maintain life on land, no special conducting systems appear. In the case of algæ, practically all of the cells take their own water and soluble materials directly through their cell walls. In true land plants, however, the body of the plant extends up into the air in contact with sunlight. It must receive mineral solutions, which are absorbed by the roots, through the medium of some sort of transportation system. Plants which have tubelike structures for conducting liquids between the roots and leaves are called vascular plants. The ferns and their allies, together with the seed-bearing plants, are of this type.

The vascular system, with its woody cellulose walls, provides vessels for the conduction of liquids. It also supplies some of the necessary strength for supporting the leaves and reproductive organs above the ground. You may see in the fern that the body of the plant consists of well-developed roots, stems, and leaves. These are the typical parts of ferns, and, as we shall see immediately, of the flowering plants with which we are best acquainted. The upright leaves of the ferns are called fronds. They are composed of leaflets in which the vascular system is represented by the veins. Leaflets have chlorophyll-bearing cells which serve purposes of food-making.

Success of the sporophyte generation. Now which generation is the conspicuous plant in the case of the fern — the sporophyte or the gametophyte? Obviously the sporophyte. You may note that the spores are borne in the little brown cases (sporangia) on the under side of some of the leaves. We find here a complete reversal of the importance and of the size of the two generations. Whereas in the liverworts the conspicuous plant was the thallus or gamete-producing plant, in the ferns the spore-producing plant is the one we call the "fern plant."

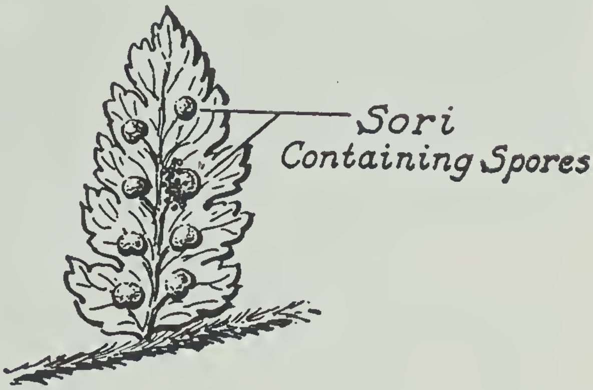


FIGURE 97. A portion of a fern frond, showing sori on the lower surface. Why is a fern ranked "higher" than a moss?

Sexual reproduction. Ferns exhibit a close relationship, however, to the simpler forms. A thallus (called, among ferns, a prothallus) is produced as the first structure when the spore

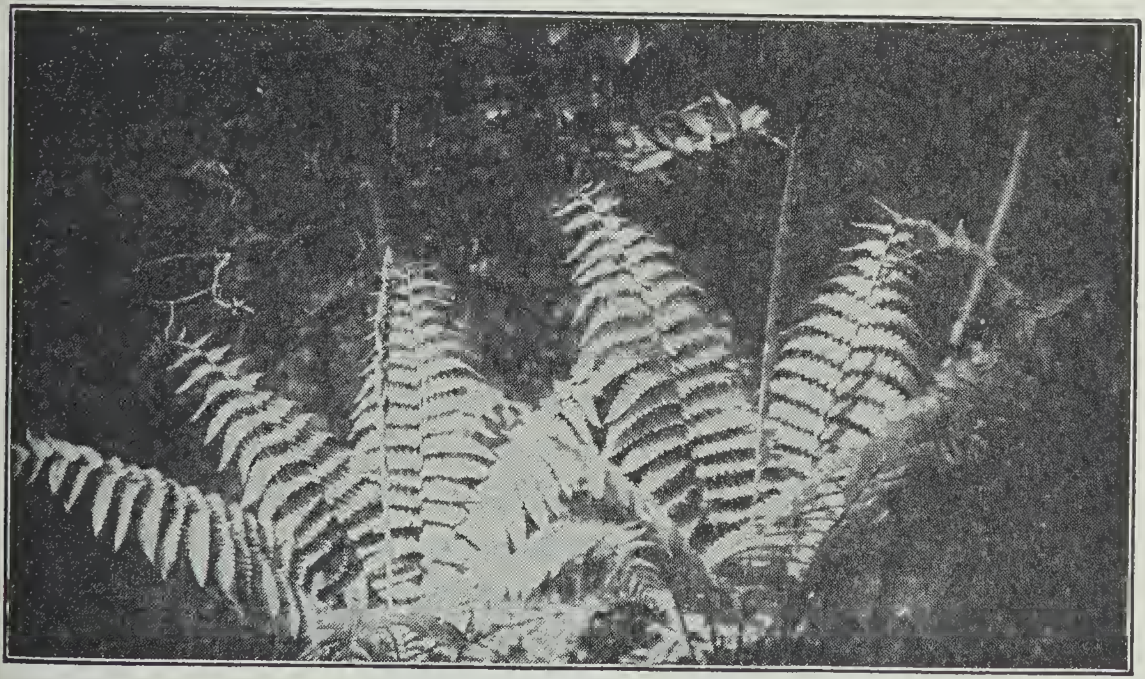


FIGURE 98. A fern. Observe the spore-bearing structures.

begins to develop into a new plant. This prothallus bears small archegonia and antheridia on the *under* surface. After the sperm produced by an antheridium has fertilized the egg cell of an archegonium, the fertilized egg cell may begin to develop on the prothallus. The embryo soon produces roots, develops a stem, and the typical body of the sporophyte generation, which thereafter is independent of the prothallus.

The sexual method of reproduction (ferns) requires that the sperm reach the egg cell by means of a water medium on the under side of the prothallus. This is one reason why most ferns do not thrive in dry habitats. They do not need shade, however, except as it conserves the moisture of the soil. Hence ferns often are found in sunny, marshy areas.

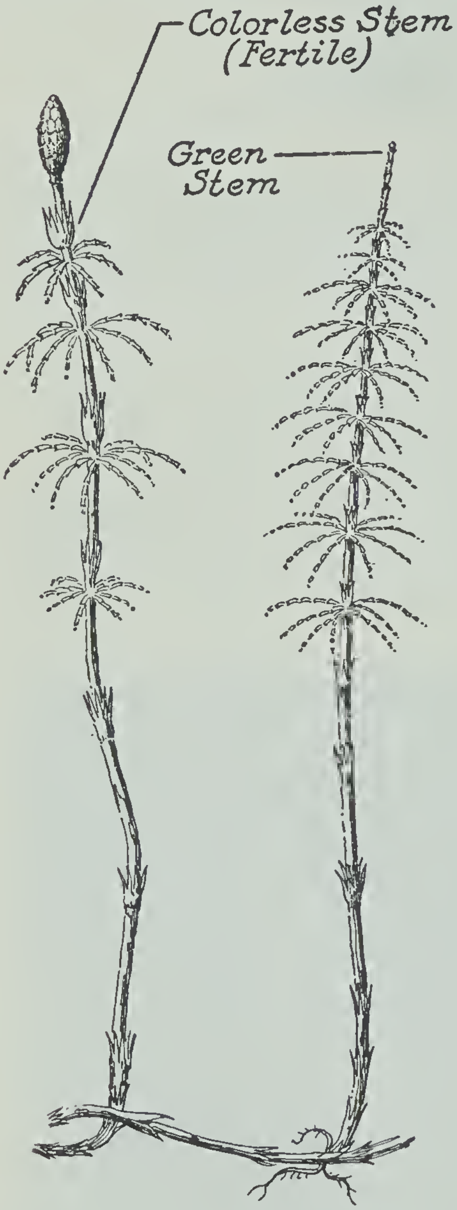


FIGURE 99. A horsetail.

Asexual reproduction. Another characteristic of ferns is the fact that the stems are mainly underground. Here they live from year to year, growing by means of buds. From these underground stems are developed the familiar "curls" or coils of "baby ferns." The latter are seen in the spring as the first signs of renewing life.

Specialization among ferns. Ferns are members of the Division Pteridophyta, and are placed higher in the scale of classification than the mosses. This is because they exhibit greater specialization of structure. We have seen that in ferns, the sporophyte generation has become dominant. It now forms the conspicuous plant body, and is active in the food-making process. Furthermore, we have noted the development of a special vascular system among ferns, which was not present in the moss plants.

Horsetails and club mosses. In addition to the ferns, the Division Pteridophyta includes two other groups, the horsetails and the club mosses. We have noted that ferns show advances over plants classified lower in the scale in the way of improved nutrition and transportation. We may note three other changes or specializations concerning the horsetails and club mosses:

1. Among horsetails certain leaf-like structures are adapted for the special purpose of bearing spores. These structures are called sporophylls.
2. Such sporophylls grow closely together to form cone-shaped masses on the ends of branches. These aggregations of such modified leaves are called strobili (singular: strobilus). Thus you see in the sporophylls *the forerunners of stamens and pistils* (parts of a flower), as developed by flowering plants. Strobili show *structural resemblance to flowers.*
3. In one of the club mosses a further advance appears. Two types of spores are produced. One kind of spore develops only into female gametophytes, and the other kind produces only male gametophytes.

SEED-BEARING PLANTS

(Illustrating the development of flowers and seeds)

The spermatophytes. We now have studied increasing complexity of structure in plants, beginning with algæ and continuing up to the "highest" group of plants. These "highest" plants are the seed-bearing plants, members of the Division Spermatophyta. The high ranking of this group is based upon the following developments:

1. Some of them grow to considerable size, and the body extends away from the surface of the earth, upward into the air, and downward into the soil.
2. The specialization of cells into tissues, organs, and systems is carried to its greatest extent.

3. The sporophyte generation is most fully developed. Sexual reproduction is carried on in a manner that is both complex and successful.
4. The majority of the species are able to carry on a successful life on land and many of them live in comparatively dry regions.

Classification of the spermatophytes. It is estimated that there are some 133,000 species belonging to this division. This comprises about half the known species of plants. They compete successfully with the other groups and are definitely "higher" in the sense that they dominate others.

Botanists divide and subdivide the group as follows:

Division Spermatophyta — Seed plants.
  Class I. Gymnospermæ (exposed seeds) — Cone-bearing plants.[1]
  Class II. Angiospermæ (enclosed seeds) — Common "flowering plants."
    Sub-class 1. Monocotyledoneæ — One-leaved embryo.
    Sub-class 2. Dicotyledoneæ — Two-leaved embryo.

The gymnosperms have seeds exposed on the strobili and hence are called gymno- (naked) sperms (seeds). The second class includes the common flowering plants, whose seeds are enclosed, hence they are called angio- (vessel) sperms (seeds). In the first group, the conifers or cone bearers are the most familiar and abundant. We are acquainted with them under the names of pine, hemlock, cedar, spruce, and the like. Practically all other trees, flowers, shrubs, fruits, and vegetables with which you have become familiar through observation and use are angiosperms.

Structures of seed plants. We can get a very good general picture of a typical seed-bearing plant by giving a moment's attention to a common tree. The plant body is supported by elements of the fibrovascular system. The characteristic parts include:

1. Roots, which push into the ground, and which absorb dissolved minerals by means of special adaptations of the epidermis called root hairs.

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[1] Also flowering plants.

2. Stems, which are green in annual plants, and are covered with epidermis or with bark. Through the stems, food materials are distributed from the roots to the leaves. In addition, food from the leaves is transported to the roots, flowers, fruits, and seeds. Some stems, such as tubers, are specially adapted for storage of food.
3. Leaves, which are adapted to expose large areas of chlorophyll-bearing cells to sunlight. This makes possible the manufacture of starches, sugars, proteins, and oils. Leaves also control, to some extent, the amount of water lost by the plant — a process called transpiration.
4. The strobili are the flowers. They have structures that enable the egg to be fertilized by the sperm without transfer through external water. Most fruits are adaptations for securing protection and dispersal of the seeds. These structures pertaining to the process of reproduction will be discussed more fully in a later chapter.

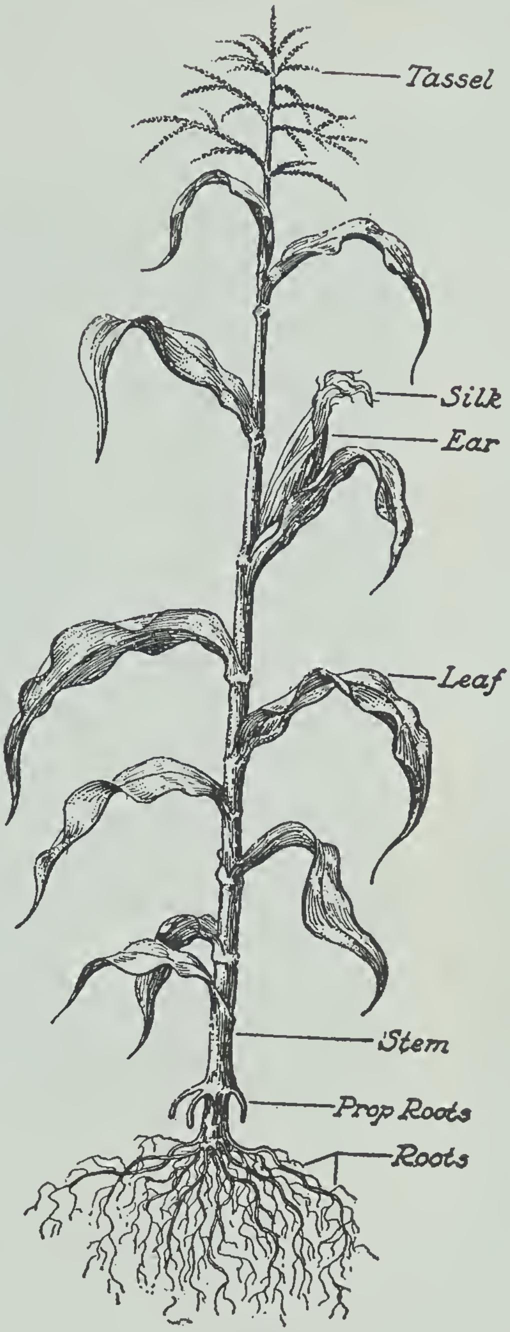

FIGURE 100. Diagram of a seed plant (corn). Is this a sporophyte or a gametophyte?

Roots. Roots assume various shapes among seed-bearing plants. Two types are common. First is that illustrated by the dandelion and the carrot, which pushes directly downward by means of a pointed cone. This type is called a tap root. The second type is called a fibrous root, which we see illustrated by the roots of grasses and corn. In general, roots are proportional in size to the body of the plant above ground. Also, in all types of roots, absorption is effected near the growing point, and usually by the root hairs (see page 216) only.

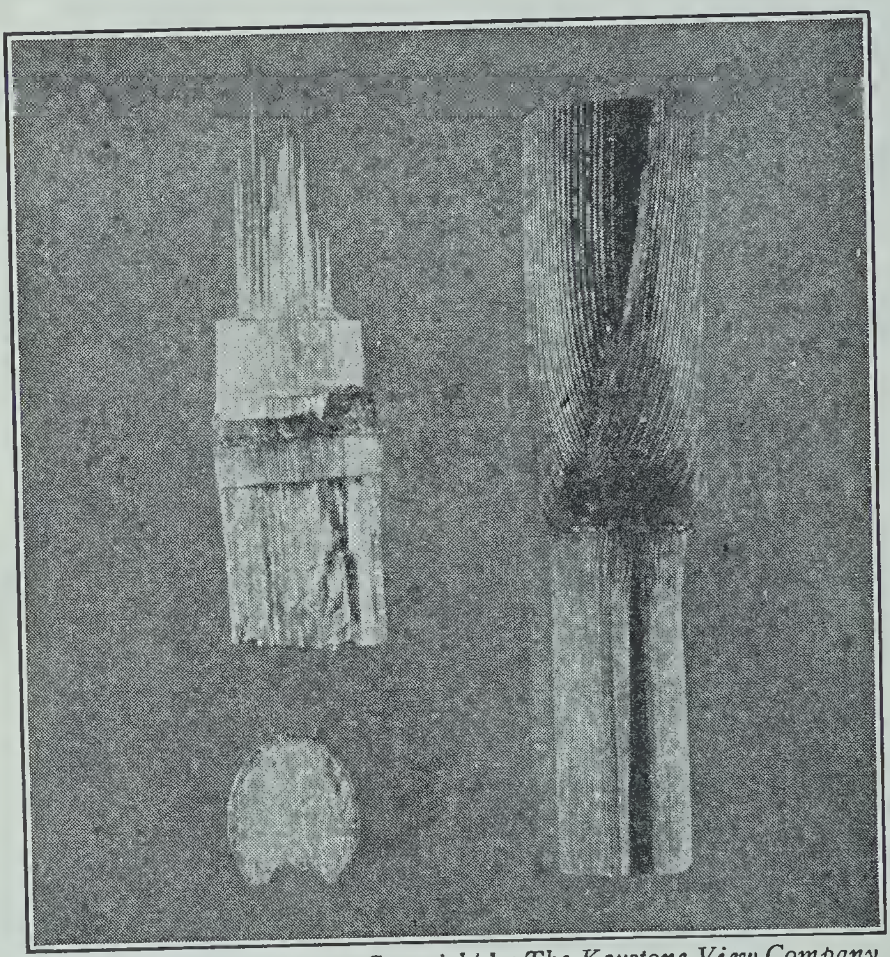

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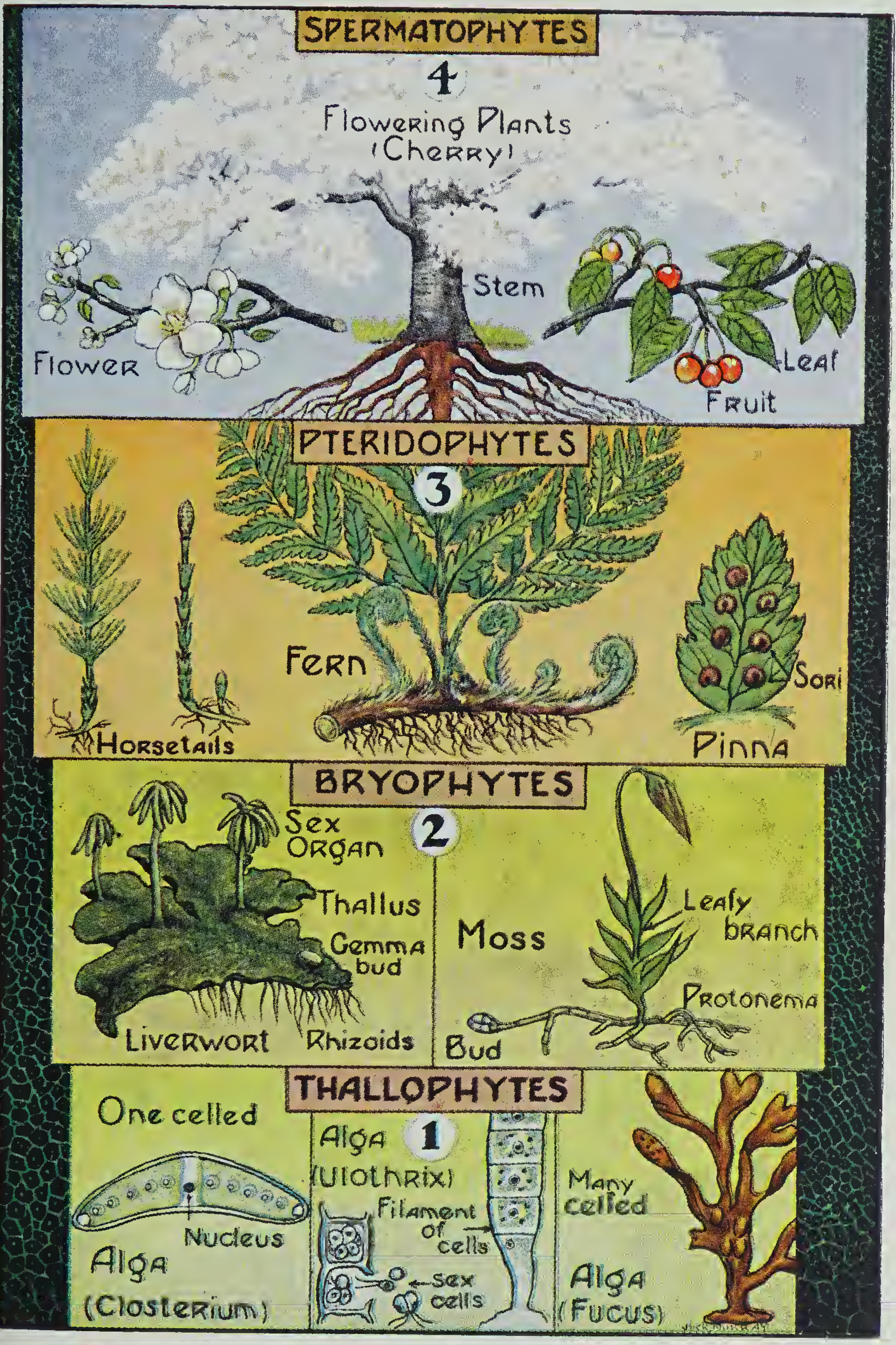
FIGURE 101. Monocot stems. What plant is this? Note the fibers at the broken end. What function do they serve?

Monocot stems. There are two general types of stems: the monocotyledonous stem and the dicotyledonous stem. The functions of all stems are to furnish support and to conduct free fluids. In the monocotyledonous type the support is furnished chiefly by a cylindrical, tubular structure, or hollow column. Bamboo and the grasses have typical stems of this kind. Engineers consider this "hollow column" structure to be a means



The Four Divisions of Plants

of construction which gives the greatest strength for the least weight of material. Bicycle frames and "jungle bars" of the playground are constructed of hollow tubes. This type of stem ceases to grow in diameter after the fibers have become "set" and of full size. Thereafter, such stems grow only in length. This type of stem does not develop "annual rings." Numerous fibrovascular bundles scattered throughout the interiors of the columns and separated by pith tissue furnish supplementary support. They also carry fluids from the tips of the roots to the stems, leaves, and buds.

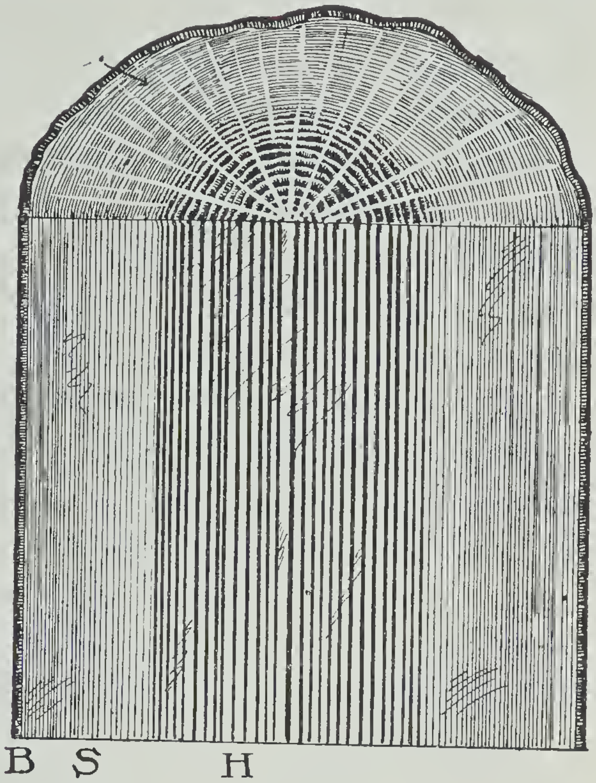


FIGURE 102. Section of the stem of a tree. About how old was this tree? What is the evidence? Is this a monocot or a dicot stem?

Dicot stem. The typical "woody stem" or dicotyledonous stem, such as that of a tree, begins development as a herb-like stem, which is a cylinder very much like the monocot stem. The dicot stem, however, continues to grow in an inner layer known as the cambium. The growth increases in both diameter and length. On the side of the cambium toward the center of the stem, xylem, or wood tissue, is formed. The xylem functions for a time in conducting liquids upward. Later it constitutes the "heart wood." Each year, in perennials (plants living from year to year), the cambium layer moves farther outward and forms

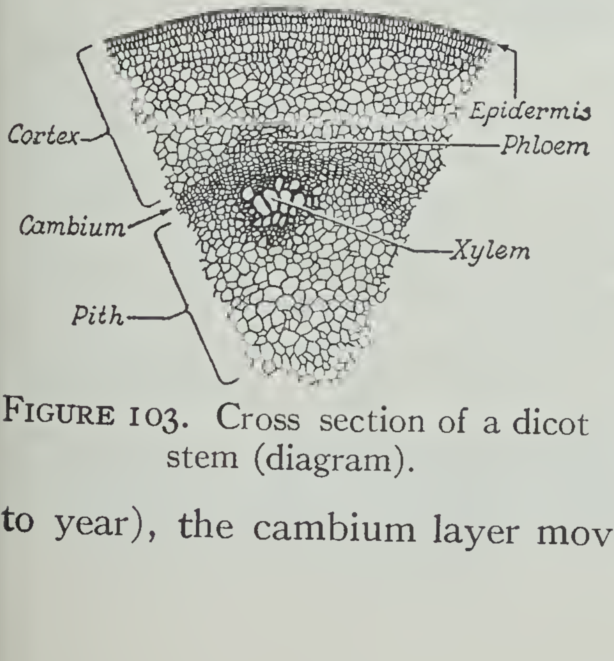


FIGURE 103. Cross section of a dicot stem (diagram).

a new layer of xylem or wood. Thus, as is shown in the diagram of a cross section, are formed the "annual rings" which mark each period of growth and provide a means for estimating the age of a tree. Since more than one growing season a year may produce more than one ring, we cannot absolutely depend upon growth rings for determination of age. The stumps of some of the sequoias show as many as 2500 of these rings. Toward the outside of the stem, the cambium forms the phloem tissue, through which, during the growing season, manufactured food materials are transported. This phloem contains bast fibers, which strengthen and support the stem.

Stems in general. Stems exhibit a great variety of adaptations. Vines, for example, form a special type which depend upon other bodies for support, but which have remarkable abilities to reach the light. Certain "rattans" attain lengths of a thousand feet. Aërial roots, underground stems, and runners which send out roots wherever they touch the ground, are interesting structures of some stems. Others will be mentioned when we consider the subject of nutrition and conduction, with which stems are particularly concerned.

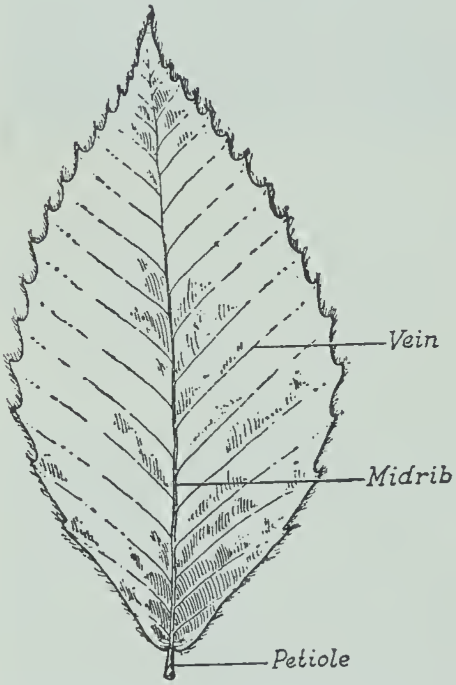


FIGURE 104. Diagram of a leaf. What is the advantage to the plant in having broad, thin leaves? What is the function of veins?

Leaves. Leaves likewise will be more thoroughly discussed under the subject of nutrition in plants. For the present try to get the general picture of the leaf as shown in the accompanying diagram (Figure 104). The leaves of monocots usually are parallel-veined, while the dicot leaves have netted veins. We have mentioned the specialization of leaves as sporophylls. In the seed plants the sporophylls give rise to the stamens, pistils, and petals of the flower. Other leaf modifications are tendrils of climbing plants, such as those on a grapevine, and the thorns of various plants. The chief functions of leaves are photosynthesis, respiration, and transpiration.

Summary. In comparing the structures of successively higher plants, we have noted a change from the simple to the complex. Most algæ are aquatic; some are single-celled, but among other colonial forms there are divisions of labor among cells. Liverworts illustrate beginnings of adaptation for land life, and alternation of generations in the life cycle. Mosses show an increasing development of the sporophyte generation, which continues among the ferns and becomes outstanding in the case of seed plants. In ferns we note the development of special vascular systems, and the development of the sporophyte as a food-making structure. The development of strobili by horsetails suggests the possible origin of flowers.

We see the culmination of these developments in the structures of seed plants. The latter are terrestrial plants, for the most part, in which the sporophyte has become the dominant generation. Seed plants have well-developed conducting systems.

The development of these specialized structures is accompanied by division of labor among cells. As in the case of higher animals, we find that higher plants exhibit increased specialization of structure and function.

SUGGESTED ACTIVITIES

Scientific methods

A scientist analyzes problems and objects into parts, for more detailed study.

1. If a specimen of Marchantia is available, identify as many as possible of the structures described on pages 167 and 168.
2. Examine a moss plant. Identify the protonema and the leafy structure. Observe how budding of the protonema gives rise to new leafy structures.
3. Examine a fern plant. See if sporangia are present on the under sides of some of the leaves. Note the development of underground stems and roots. Compare the fern with horsetails and club mosses if the latter are available.

4. Obtain specimens of a liverwort, a moss, a fern, and a seed plant. Press and mount on a large card. Label so as to indicate the distinguishing characteristics of each group represented.
5. Examine a seed plant. Identify the root, stem, leaves, flowers, fruit, and seeds, or as many of these structures as may be represented in the materials at hand. Prepare a report which discusses the functions of these structures.
6. With the aid of a microscope or microprojector, examine a cross section of a monocot stem. Note the structures described on page 178. Prepare a labeled sketch.
7. With the aid of a microscope or microprojector, examine a cross section of a dicot stem. (Compare with Figure 103.) Describe the structures discussed on pages 179 and 180. Prepare a labeled sketch and compare it with the sketch of a monocot stem.
8. In a table of four vertical columns compare a liverwort, a moss, a fern, and a seed plant as to the following characteristics: gametophyte generation, sporophyte generation, presence or absence of flowers and seeds, and development of special structures for the conduction of liquids.

SUMMARY OF PRINCIPLES

1. Liverworts show adaptations for both aquatic and land life.
2. Reproduction among some liverworts involves two body forms — the sporophyte and the gametophyte. This phenomenon of two forms (sporophyte and gametophyte) is characterized by the expression "alternation of generations."
3. Mosses are able to live successfully with less moisture than is necessary for the success of liverworts.
4. A moss exhibits a structure called the protonema, and rhizoids for more successful absorption of food materials.
5. Among mosses the sporophyte generation is better developed than in the case of liverworts.
6. Moss sporophytes usually contain chlorophyll.
7. Ferns and horsetails develop the sporophyte as the most conspicuous generation.
8. A vascular system for conduction of liquids first appears among the ferns.
9. Seed-producing plants are of two types, the gymnosperms and the angiosperms.

10. The development of plants from lower to higher types seems to be in the direction of increasing ability to live on land, increasing importance of the sporophyte generation, and development of a more specialized "vascular" system.

GUIDE QUESTIONS

1. Name two examples of liverworts.
2. Why is Riccia able to live on a moist soil?
3. Describe two methods of reproduction in Marchantia.
4. Explain what is meant by "alternation of generations."
5. What is one difference between mosses and liverworts?
6. Describe the common manner of growth in the case of mosses.
7. Describe two structures exhibited by mosses which mark an advance in adaptation for land life.
8. What change in the sporophyte generation among mosses indicates the possibility of living independent of the gametophyte?
9. Define the functions of the antheridium and archegonium in mosses and liverworts. What cells are produced by each?
10. What two tendencies exhibited by mosses do we find carried further among ferns?
11. What additional adaptations for land life are exhibited by ferns?
12. What is a vascular system? Name two functions of this system.
13. Which generation is most conspicuous among ferns?
14. Describe the method of vegetative reproduction among ferns.
15. What are "fronds"? "prothallia"? "sporangia"?
16. Would a shaded habitat be essential to the successful growth of ferns?
17. Give four reasons for ranking seed plants "highest" among the plant groups.
18. Name five plants that are gymnosperms and five that are angiosperms.
19. What are the two chief types of roots? What are the functions of roots?
20. Discuss the two classes of stems and describe the structures of each.
21. Name the parts of the dicot stem having each of the following functions: (*a*) growing, (*b*) carrying liquids downward, (*c*) carrying liquids upward.
22. What functions are carried on by leaves?
23. To what extent do plants exhibit increased complexity as one successively examines higher types?

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UNIT III

LIFE FUNCTIONS

IN THE preceding unit we have learned that all organisms have certain characteristics in common, or that there is a unity of life. We also have noted that organisms differ from each other in many respects, or that there is diversity of life. There are simple organisms, some of them single-celled. There also are very complex organisms, composed of many cells. In the complex organisms we have found that there is division of labor among the cells; that cells have become specialized. These studies have been concerned largely with structure, or anatomy. We now must learn how these structures carry on their functions. The study of function is called physiology.

How does the organism obtain food, and for what functions is food used? What is energy? What relationship does energy have to digestion, growth, repair, muscular activity, respiration, circulation, and excretion? What is the relationship of energy to metabolism, and how is metabolism regulated within an organism? From what source do plants and animals obtain energy? What is the relationship of the nervous system to other activities in the animal body? These are some of the questions concerning functions that we must attempt to answer.

The subject of Unit III is, then, physiology, or the study of function. Physiology has had its greatest development as a science in comparatively modern times. The natural historians of Greece and Rome had studied plants and animals, to be sure, but largely from the standpoints of structure and classification. Physiology received small attention prior to the fall of the Roman Empire, and little or no progress was made during the Middle Ages.

During the Middle Ages (medieval times) there was a marked tendency to depend upon written records, such as the works of Aristotle and Galen, as sources of information. Galen (131–201) was a Greek physician who lived in Rome, and who was responsible for most of the knowledge concerning human physiology then in existence. Some of his statements, however, were in error.

As an example, Galen had stated that there were small openings between the right and left ventricle of the human heart, through which the blood passed. It was not until 1543, over thirteen centuries after the death of Galen, that this statement was questioned by the Belgian anatomist, Andreas Vesalius. Vesalius was loath to say that Galen was wrong, and that there were no pores connecting the ventricles of the human heart. In fact such a statement might have been dangerous. Servetus of Vienna stated bluntly that Galen was wrong about the structure of the heart, and Servetus was burned at the stake in 1553 because he had questioned authority, in this and in other matters.

In spite of the general opposition to new knowledge and to scientific experiments which existed during the Middle Ages, we find it hard to realize that demonstration of the circulation of the blood did not occur until William Harvey published his monograph in 1628.

Vesalius and Harvey laid a foundation of scientific observation and experimentation which has been expanded by the works of others, and today physiology is one of the important and rapidly developing fields of biology.

CHAPTER XI

ENERGY AND LIFE ACTIVITIES

Problems:

1. How do plants and animals obtain energy for their activities?
2. What are the specific uses of foods?

THE ACTIVITIES OF ORGANISMS REPRESENT ENERGY CHANGES

Lavoisier. The French chemist, Antoine Laurent Lavoisier (1743–1794), has been called the Father of Nutrition. Some of his experiments had to do with the use of energy in the animal body. He found that animals used oxygen and gave off carbon dioxide. Lavoisier knew that when a substance burned in air it combined with oxygen. This process of combining with oxygen is oxidation. Lavoisier suspected that heat formation and other activities within an organism were related to the same process — oxidation.

Oxidation. We now know that all activities of organisms represent energy transformations (changes). Compounds are oxidized within the bodies of organisms. As a result, heat and energy for carrying on metabolism are made available. Oxidation cannot occur unless oxygen is present. This is why oxygen is so necessary in the lives of organisms. Without oxygen, metabolism would cease. The energy in food and protoplasm could not be used.

Energy. Energy may be defined as the capacity to do work. It may be measured in heat units or in foot-pounds. These units of measurement are as follows:

1. The calorie (large): the heat energy necessary to raise the temperature of one kilogram of water one degree centigrade.
2. The foot-pound: the energy necessary to lift one pound through a vertical height of one foot.
3. One calorie is equal to 3080 foot-pounds.

Biologists usually employ the calorie as a unit of energy.

Life activities involve energy in several forms, but heat energy is easily measured. Other forms of energy may be evaluated in terms of heat. We say that a gram of sugar contains about four calories, and a gram of fat contains about nine calories. This means that when oxidized a gram of fat will yield over twice as much energy as will a gram of sugar.

Respiration and oxidation. The process of taking oxygen into the cell, and giving off carbon dioxide from the cell, is called respiration. Respiration includes the combining of oxygen with protoplasm — sometimes called the oxidation of food. Amœba, algæ, earthworms, frogs, trees, insects, and human beings alike carry on respiration.

Breathing. Breathing is not a general life function; it should be distinguished from respiration. Many organisms do not breathe — for example, Amœba or Spirogyra. Breathing is limited to certain animals such as man. In breathing (man) air enters the body through the nose or mouth. The air is then drawn into the lungs because of muscular expansion of the chest. Then the gases are exhaled. Thus breathing is preliminary to and subsequent to respiration. Breathing is sometimes referred to as "external respiration." *Some* animals breathe — plants do not.

FOOD IS ESSENTIAL TO METABOLISM

Energy and metabolism. We have learned that metabolism is the sum of all of the processes that function within the organism. Metabolism has two phases: the building-up process which is called anabolism, and the tearing-down process which is called katabolism. The activities involved in metabolism make necessary the use of a large amount of energy. This energy must be supplied and constantly renewed.

Suppose, for instance, that we walk up several flights of stairs. In so doing, a large number of muscle cells are contracted and relaxed, not once, but many times. Each time that a muscle cell contracts, a certain amount of energy is used. This energy comes from stored food or protoplasm. It must be renewed if the muscle cell is to continue its function for any great length of time. Waste products must also be removed.

In walking upstairs some of the muscle cells may be injured through use, or as the result of an accident such as striking some object. These injured cells must be repaired or replaced from some source. The act of walking upstairs, then, involves the tearing-down process of katabolism. Energy is used, and cells may be injured or destroyed. The renewal of energy and the repair or replacement of cells are processes of anabolism. It is from food that the organism obtains the materials that are oxidized to provide energy, or are used in building and repairing cells.

Growth. Most organisms pass through a period of rapid growth in early life. During this period anabolism is much more effective than is katabolism. Obviously, a considerable amount of food must be available to the young, growing organism. And such is the case. The seed of the plant contains quantities of stored food which make possible rapid development of the young plant. The eggs of many animals contain stored food upon which the young animals subsist until they are hatched.

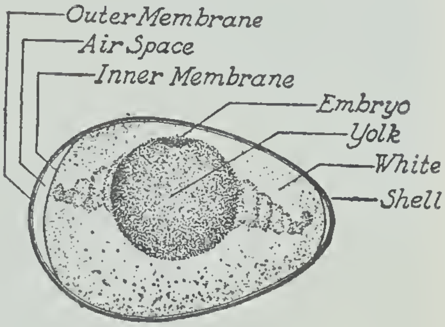
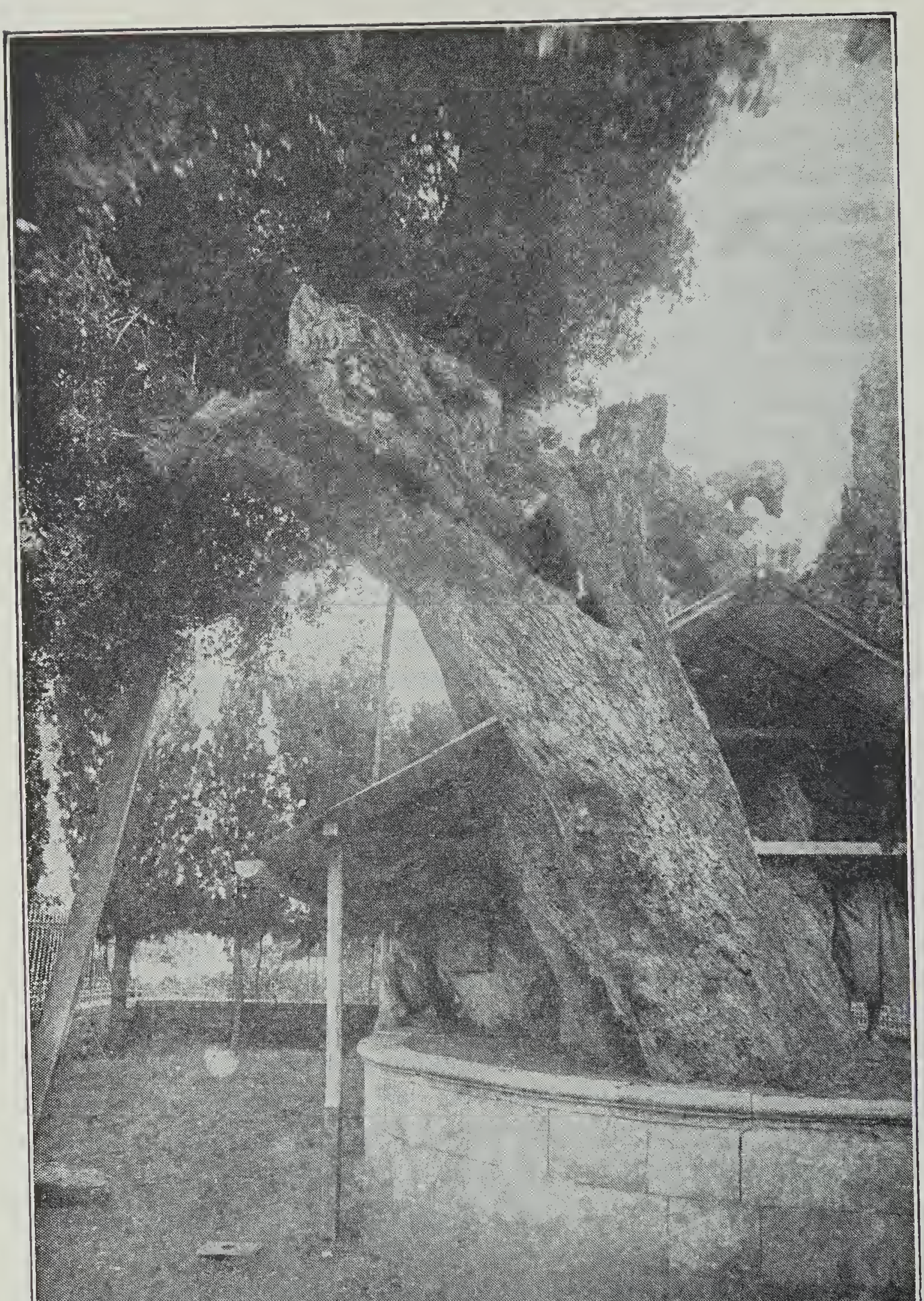


FIGURE 105. Diagram of an egg. The yolk and white consist largely of stored food materials.

Repair. After an organism has attained full adult size, the process of anabolism may slacken somewhat. No longer is it necessary to build or add to structures, but merely to repair them and to maintain a constant supply of energy. In old age, katabolism becomes more active than anabolism. Injured cells may not be replaced or repaired, and the supply of energy is limited. Thus we find that an old tree may become hollow or that branches may die. This really means that the cells of these structures have died, one by one, and have not been replaced or repaired.

Foods. We can summarize our ideas of foods by saying: A food is any material which contains substances that may be used by an organism for growth, repair, or any other process that involves the use of energy.

Most foods are mixtures of many substances. Some of these



By Ewing Galloway, New York.

FIGURE 106. A decaying tree. Which process, anabolism or katabolism, is most evident here?

substances are used by the organism and others are useless. For example, if you eat an apple, you swallow some water, some mineral salts, some sugar, a small amount of protein, and considerable fiber. All except the fiber may be used by the body. The fiber passes through the digestive canal without contributing to the functions of growth, repair, or production of energy.

The cell walls of most vegetable foods and the vascular tissues of plants generally contain the substance known as cellulose. While certain animals — the horse, for example — may digest this fiber, man cannot do so. These indigestible parts are known as roughage. A certain amount of roughage seems to assist in the movement of food through the digestive canal.

The usable parts of food consist of a few groups of substances called nutrients. The common nutrients are carbohydrates, fats, proteins, water, and certain mineral compounds. These substances are known to be used in the processes of metabolism.

CARBOHYDRATES AND FATS ARE OXIDIZED TO PROVIDE ENERGY

Sugars and starches. Simple sugar is the basic product of food manufacture in green plants. Simple sugar is converted into starch for storage purposes. The large amount of starch in ordinary potatoes represents stored food. Sugars and starches are carbohydrates. All of our carbohydrate foods owe their origin to the simple sugar manufactured by green plants.

Carbohydrates and energy. In the cells of organisms, carbohydrates are used to a limited extent for purposes of growth and repair. Their chief value, however, is due to the fact that they are oxidized to provide energy. For this reason they are called "fuel foods."

Fats and energy. Fats are also known as fuel foods. They are found both in plants and in animals. When oxidized, they supply energy for work. Fat is a common storage form of food material, and stored fat represents a reserve supply of energy. We are familiar with some fats, such as plant oils, and the fat found in beef, chickens, ducks, or pork.

PROTEINS ARE USED IN FORMING CELL STRUCTURES

Proteins and cell structures. To a large extent, proteins are utilized in the growth and repair of cells. The materials of active cells are constantly being worn out and must be replaced. For this reason, a supply of protein is necessary throughout the life of the organism.

Green plants make sugars, fats, and proteins. Animals, which do not contain chlorophyll, cannot synthesize these substances from inorganic compounds. Nor can the animal body convert sugars into proteins. Man must obtain a supply of protein by eating foods which contain proteins. Excess proteins, however, can be oxidized to supply energy in the human body.

WATER HAS MANY USES IN PLANTS AND ANIMALS

Uses of water. We have learned that water is a part of the living substance protoplasm. The water content of organisms varies, depending upon the species, the individual, and the part of the body in question. Water content may also be influenced by changes in the environment. Since water is a part of the living substance it is necessary to the growth and repair of cells.

In the bodies of complex organisms, water has many special functions. For instance, it serves as a solution medium in the digestion and transportation of foods. It also serves as a medium in which some wastes and excess heat are removed from the bodies of organisms.

SOME MINERAL COMPOUNDS ARE NECESSARY TO LIFE

Both plants and animals require certain mineral salts. This should not be surprising in view of the fact that protoplasm contains mineral compounds. Such mineral compounds are those containing calcium, potassium, iron, chlorine, phosphorus, sodium, iodine, sulphur, and magnesium. They are not oxidized to provide energy, but they are used in the formation of tissues.

Mineral compounds and growth. The need for mineral compounds is most marked during periods of growth, when new cells and tissues are being formed. In the human body, for instance, salts of calcium and phosphorus enter into the formation of the bony skeleton. Hæmoglobin of the blood contains iron, and plasma contains such mineral salts as sodium chloride. A supply of these materials must be available during growth, if the structures in question are to develop normally. The need for mineral compounds does not end with the period of early growth, although this need usually is less evident in the adult organism.

Summary. In summarizing, we see that the life activities of plants and animals represent energy transformations. Green plants utilize the energy of sunlight in food-making. Food[1] may be oxidized in both the plant and the animal body to liberate energy for carrying on life activities or functions. Respiration is a process which includes the oxidation of protoplasm and therefore is necessary to the release of energy.

Seeds and eggs often contain stored food which is used by the young plant or animal in building tissues or providing energy. When this supply of food is exhausted, food must be obtained from other sources, for food supplies the energy used in metabolism.

Foods are usually mixtures of substances containing such nutrients as carbohydrates, fats, proteins, mineral compounds, and water. We find that proteins are used in building cell structures, and are oxidized to provide energy. Carbohydrates and fats are fuel foods, being sources of energy for work. Water makes up a large part of the organism, and has many uses within the body. Certain mineral compounds are necessary to the well-being of both plants and animals.

SUGGESTED ACTIVITIES

Scientific methods

A scientist reviews and repeats observations for the sake of establishing their accuracy.

1. Prepare a table indicating how several organisms, such as algæ, trees, frogs, tadpoles, fish, and earthworms obtain oxygen.

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[1] The "food" has been incorporated in cells, and may be regarded as protoplasm.

2. After consulting the reading references at the end of this chapter, investigate the development of the respiration calorimeter. Prepare a report accompanied by a diagram or model of the apparatus.
3. Devise and perform an experiment to determine the amount of (*a*) water, and (*b*) mineral matter, in a potato.
4. After consulting the reading references at the end of this chapter, prepare a table showing the comparative water content of a number of organisms.
5. Discuss why the animal body requires a certain amount of protein food.

SUMMARY OF PRINCIPLES

1. The activities of plants and animals represent energy transformations.
2. Energy is liberated from protoplasm (stored food) by oxidation.
3. Food is necessary to metabolism. Food supplies the energy and material for growth and repair, and for other organic functions.
4. Nutrients include carbohydrates, fats, proteins, mineral compounds, and water.
5. Carbohydrates and fats are used chiefly for their fuel value, and not as builders of tissue (in man).
6. Proteins furnish materials for the growth and repair of cell structures. They also may be oxidized to supply energy.
7. Water serves as a solution medium in the organism. It is an essential part of protoplasm.
8. Mineral compounds, being represented in protoplasm, are necessary in the formation of cells and tissues.

GUIDE QUESTIONS

1. Why do we say that the activities of organisms represent energy transformations?
2. How is oxidation related to the use of energy in the organism?
3. What is meant by the statement that a gram of sugar contains 4.1 calories?
4. Why is food necessary to metabolism?
5. At what period in the life of an organism does anabolism predominate over katabolism?
6. Can all substances eaten by animals be classified as foods?
7. What is the relationship between respiration and oxidation?
8. What uses are made of fats, carbohydrates, and proteins in plant and animal bodies?

9. Discuss the uses of water in organisms.
10. Why are certain mineral compounds necessary to growth and repair in organisms?

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Chapter XII

METABOLISM IN PLANTS

Problems:

1. How do green plants manufacture food?
2. How is food-making related to growth?
3. How do plants which do not contain chlorophyll obtain food?
4. Do plants exhibit adaptations which are related to problems of nutrition?

Foreword. Our study of energy and food recalls to us the interrelations of plants and animals in the fresh-water pond. We may remember that green plants manufacture their own food, and provide the basic food supply for other organisms. We have learned that animals are basically dependent upon green plants for their food supply.

MANY PLANTS OBTAIN FOOD WITHOUT MOVING ABOUT

Locomotion in plants. We may begin our study of plant nutrition by recalling that many plants are unable to move from place to place. Some of the small, simple plants, such as Oscillatoria, certain swarm spores, Euglena (sometimes classified as an animal), and many kinds of sperm cells of plants, have limited powers of locomotion. One of the special structures developed by simple plants, such as algæ, is the "holdfast," as in the case of Ulothrix. Other species of plants develop such structures as rhizoids, taproots, and fibrous roots.

Many plants carry on their life activities in a fixed location. This fact is reflected in the structures which such plants possess. These structures enable the plants to obtain food without moving from place to place.

SUNLIGHT IS THE SOURCE OF ENERGY IN FOOD MAKING

The source of energy. It has been stated that the energy used in food making comes from the sun. To learn the facts we may wish to make some experiments. First of all, let us study the green plant and its food-making process in relation to sunlight.

Experiments on food making. Keep a green plant such as a geranium in the dark for twenty-four hours. Much of the food that is stored as starch in the leaves will be transported or consumed. Now remove a leaf from this plant and extract the green coloring matter (chlorophyll). This may be done by heating the leaf in alcohol (use a water bath), for about five minutes. Then wash the leaf in water and test for the presence of starch by placing the leaf in a dilute solution of iodine (the presence of starch is indicated by a bluish color). Now allow the plant to remain in sunlight for two or three hours. Then remove another leaf and test it in the same manner. Are the results the same in the two cases, and if not, how may we account for the difference? What is the "control" in this experiment?

A similar experiment may be performed by placing another geranium plant in the dark for twenty-four hours. Then cover a portion of a leaf with cork or tin-foil and expose the plant to sunlight for two or three hours. Remove the leaf in question, extract the chlorophyll as in the above experiment, and test with dilute iodine solution for the presence of starch. Do the covered and exposed parts of the leaf react in the same way? What is the control?

A third experiment has to do with the presence or absence of chlorophyll in relation to the food-making process. Select a geranium plant (silverleaf geranium) which has variegated (green and white) leaves. Keep the plant in the dark for two or three days before performing the experiment. Sketch the outlines of the green and white areas of a leaf on a piece of paper. Place the plant in sunlight for two or three hours. Remove one of the leaves, and after extracting its chlorophyll, make the iodine test for the presence of starch. Is there any difference between the reactions on different parts of the leaf? Compare the outline shown by the iodine-starch reaction with the sketch made of the green and white areas. In which area was food manufactured?

The results of these experiments suggest that light (sunlight) and chlorophyll are necessary to the food-making process. Sunlight furnishes the necessary energy, but the food-making reaction does not occur unless chlorophyll is present.

Leaves. In many higher plants the leaves are centers for food manufacture. A continuous layer of epidermal cells forms the outer covering of the leaf. (See figure 107.) Here and there are small openings on the epidermis called stomata. Some leaves have most of the stomata on their upper surfaces, some have most of the stomata on their lower surfaces, and in some the stomata are found on both surfaces. These stomata permit gases to enter and leave the leaf. A cross section of a leaf (see figure) also may show one or more veins. The veins are pathways by means of which certain raw materials may come to the leaf from the roots and by which food may be distributed to various parts of the plant. The cells which more or less fill the interior of the leaf are the chlorenchyma cells. Where they adjoin the upper epidermis these cells form a palisade-like layer, known as the palisade chlorenchyma. Below this layer, the chlorenchyma cells are irregular in shape and there are many air spaces between them. This lower region is called the spongy chlorenchyma.

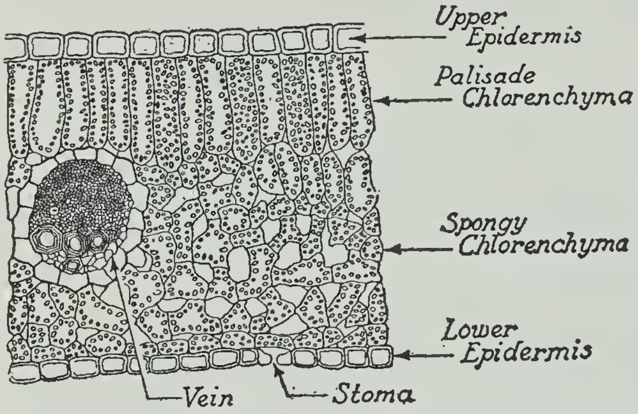

FIGURE 107. Diagram of the cross section of a leaf. In what region (tissue) is food manufactured most rapidly?

Mechanics of food-making. The chlorenchyma cells are of special interest because they contain chloroplastids, and these structures contain chlorophyll. Such cells engage in the process of making food from the inorganic compounds carbon dioxide and water. Carbon dioxide enters the leaves by way of the stomata, and excess oxygen and water vapor pass out through the same openings. Water is absorbed in higher plants by roots and thence transported to the leaves. In plants without roots other adaptations make water available to the chlorenchyma cells. In the presence of the energy-providing sunlight, a chemical change takes place in which a simple form of sugar is made from water and carbon dioxide.

Chemical action. The essential reaction in photosynthesis is as follows:

Water + carbon dioxide ⟶ simple sugar (glucose) + oxygen.

In chemical symbols we have the equation:

$$6\ H_2O + 6\ CO_2 \longrightarrow C_6H_{12}O_6 + 6\ O_2.$$

This reaction is of great importance because in it we find the origin of all food available to living things. It should be understood that all the chemical changes which occur in food-making are not indicated by this one reaction. It is probable that both the water and the carbon dioxide are first broken down and then reassembled. Perhaps one of the intermediate products is formaldehyde (CH_2O), which can be made by chemists from its elements, and by an involved process converted into sugar. Whatever may be the steps in the process, it is certain that sugar, and ultimately starch, are products of food-making in plants. Glucose ($C_6H_{12}O_6$) is a form of simple sugar that commonly is manufactured by plants.

Nature of chlorophyll. The chemical nature of chlorophyll is the subject of intensive research. It recently has been reported to exist in two forms, with formulas represented by $C_{55}H_{72}O_5N_4Mg$ and $C_{55}H_{70}O_6N_4Mg$. Chlorophyll acts as a catalytic agent,[1] to transform the raw materials carbon dioxide and water into carbohydrates.

Photosynthesis in general. We can summarize the foregoing facts about photosynthesis as follows:

1. The energy for food making comes from sunlight.
2. The green plant uses carbon dioxide and water as raw materials in food manufacture.

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[1] Chlorophyll must be present if the reaction is to occur, but chlorophyll itself remains unchanged. A catalytic agent is a substance which influences chemical action without itself being permanently changed.

3. Chlorophyll acts as a catalytic agent in the process of food-making.
4. The green plant converts carbon dioxide and water into simple sugars; oxygen is a by-product of the reaction.

Adaptations of leaves. Several physical principles are involved in the functions of leaves. First, their surface area is very large in proportion to their weight. This results in a maximum exposure to sunlight of those cells which are to manufacture food. Second, leaves generally are sensitive to sunlight and react to it by movement so that the food-making cells receive the light at favorable angles. Third, the leaf arrangement of nearly all plants is such that one leaf does not interfere with another in the matter of coming in contact with sunlight. Fourth, certain cells called guard cells are sensitive to supplies of water within the leaf, as well as to conditions in the air without. The pores or openings surrounded by these guard cells are called stomata (singular, stoma). Their opening and closing controls to some extent the excretion of water and oxygen, and the entrance of carbon dioxide. Their behavior is more closely related to the processes of respiration and conduction, and they will be discussed later in connection with these functions. Fifth, the epidermal cells of leaves form a protective covering, which is almost waterproof and airproof, except at the openings just mentioned. This is in part due to the presence of waxes and oils developed by the epidermal cells. Sixth, the veins of leaves connect with the transportation system of the stems and roots. Hence all cells may get their supply of water, and may readily dispose of their products.

Starch. In the preceding experiments we tested for starch in the leaf, but in discussing food-making we gave a chemical equation for the formation of sugar. One reason is that starch is more easily tested for in the leaf than is sugar. But in addition, although simple sugar is produced in photosynthesis, it is converted into starch in most cases before being stored. This change is expressed as follows:

$$\text{X } C_6H_{12}O_6 \text{ (glucose) yields } (C_6H_{10}O_5)_X \text{ (starch)} + \text{X } H_2O \text{ (water)}$$[1]

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[1] The number represented by X may vary.

When reconverted into glucose, the reaction is:

$$(C_6H_{10}O_5)_X \text{ (starch)} + X(H_2O) \text{ yields } X(C_6H_{12}O_6)$$

Carbohydrates can be stored best in insoluble form such as starch, but can be conducted best and absorbed by active cells only in soluble form, such as glucose. The change from starch to sugar is readily brought about by enzymes. This may be called digestion. The change from sugar to starch, and the reverse, occurs in the leaf, and elsewhere in the plant.

Fats and proteins. We have considered the formation of glucose and starch, both of which are carbohydrates. Green plants are able to convert carbohydrates into fats. This is indicated by the fact that fats are found in plant tissues. The green plant may also convert carbohydrates into protein, by adding nitrogen and perhaps sulphur, phosphorus, and other elements. Such changes doubtless are accomplished with the aid of enzymes.

Leafless plants. Many green plants are much simpler than the plants which bear leaves. As we have seen in the case of Closterium, even a single-celled organism may carry on photosynthesis if it contains chlorophyll. A good many of these simple species live in fresh water or in the sea. It is largely such species that furnish the basic food supply for aquatic organisms, by their food-making activities.

Thus we see that green plants are able to make foods from inorganic materials by using the energy of sunlight. Some plants possess special structures, such as leaves, which are centers for food manufacture. Roots are involved in the absorption of raw materials from the soil. Once food has been made, it is a potential source of energy for the plant itself, or for an animal which may eat the plant.

FOOD-MAKING IS RELATED TO GROWTH

Food, growth, and storage. The food manufactured by plants serves the nutritional needs of the individual first of all. The excess is stored. During the daytime, the green leaves manufacture more glucose than is necessary for the immediate demands of metabolism. The excess may be converted into starch, protein, or fat. In one or all of these forms it is stored in various groups of cells adapted for that purpose. The latter cells, for the most part, are not the ones which manufactured the food. At night, when no food is being made, metabolism proceeds and some of the stored food is utilized.

The growth of various parts, particularly those structures concerned with reproduction, continues day and night during the seasons when conditions are favorable. This growth requires that some food be converted into protoplasm and some be oxidized to provide energy. However, most plants living under favorable conditions manufacture more food than is necessary for their maintenance.

Roots and storage. The ability to store food in the roots is associated with length of life of the plant. Storage of food in roots occurs chiefly in the cortex. This region is composed of thin-walled cells lying between the epidermis and the central cylinder of fibers.

Annuals and biennials. Plants sometimes are classified as annuals, biennials, and perennials. An annual is a plant which, like some beans, goes through its complete life cycle in one season. It dies when it has completed the function of reproduction. A biennial is a plant, like the parsnip or onion, which lives in two growing seasons. Such plants make food and store it in the roots or stems during the first season. The next season they utilize some of the stored food to develop the structures and processes involved in reproduction.

Perennials. Perennials are plants which, like common trees, live from year to year. Many smaller plants, such as some grasses and dandelions, are perennials also, although their conspicuous bodies above ground die when frost comes. In perennials, life is maintained during the winter through use of food stored in the roots, stems, buds, etc. The "tapping" of maple trees in the early spring, with which we are all familiar, is based on the fact that at this time sap begins to rise in the stems, and food comes out of storage. Can you explain now why sap is sweet?

Stored food may be used by the plant or its offspring. Two principles apply to the storage of food. We have just seen that

By Ewing Galloway, New York.

FIGURE 108. Collecting sap from sugar maple trees in New Hampshire. At what season of the year is this done?

some perennial plants and biennial plants store food in the roots, for the most part. In other perennials, trees for instance, a good deal of food may be stored in the portion of the plant that is above ground. This serves as a ready-to-use source of energy for the next season, and nourishes those cells which maintain a sluggish activity during the winter. The first principle then is: *Plants whose individual life will continue during another season store some food in roots, stems, buds, underground stems, etc., which food is utilized for growth the following year.*

On the other hand, we find that some plants complete the individual life cycle in one growing season. For example, in the cases of beans and other garden vegetables such as corn, tomatoes, and peas, food is not stored to any great extent in the roots, but is stored in the seeds and fruit. To be sure, apple trees, cherry trees, and other well-known perennials likewise store food in the fruit and seeds. Biennials, during their second year, withdraw food from the roots and store it in seeds and fruit. The food stored in seeds serves the new generation that arises from the seeds. Thus we may state as a second principle: *That food which is stored in seeds serves for the continuance of the species.*

Growth and temperature. Growth of plants is the normal result of successful nutrition, but the rate of growth is affected by temperature. In temperate zones we say that plants grow best in warm weather. But what is the most favorable temperature for growth? Experiments with varying temperatures show that there are temperatures above which, and below which, the growth of certain plants ceases. Probably there is an optimum, or best temperature, for each species, subject to variation because of other factors such as water supply. It has been suggested that for common plants the minimum temperature favorable to growth is 5° C., the most favorable temperature about 30° C., and the maximum favorable temperature about 40° C.

Light and growth. Contrary to what might be assumed, experiments show that some plants do not grow best, or produce the most food, in the brightest sunlight. Many plants grow most rapidly at night, when loss of water is least. The food is made during the day, but utilized both day and night.

Water and growth. Water conditions of both air and soil are related to the growth of plants. Gardeners recognize that "muggy" days are favorable to growth. In general, when other conditions are the same, moisture-laden air is more favorable to growth than is dry air. Since the water for photosynthesis gains entrance through the roots, the soil must be able to furnish it. Moreover, the movement of mineral compounds and manufactured foods is by means of water solution. For this purpose much more soil water is needed. This aspect of the water problem will be discussed more fully in the following chapter when we consider conduction of liquids in plants.

Minerals and growth. All the elements found in protoplasm, except carbon and oxygen, ultimately come from the soil. In the case of water plants these elements are available as compounds dissolved in the water. In the case of land plants, the mineral compounds must also be in solution before the roots are able to absorb them. Different soils are found to be suitable for different crops. One of the achievements of scientific agriculture is the determination of the mineral requirements of certain plants. Fertilizers are mixtures of compounds such as those which contain phosphorus, potassium, nitrogen, and calcium. These are mixed in different proportions for different crops.

Field experiments. Soil analysis alone cannot determine what is best for a certain kind of plant. Experiments in growing with different fertilizers must be made. This is done on a large scale at experiment stations. It may be done in a school garden, however, or even with plants in small boxes or flower pots. The essentials of such an experiment are:

1. Provide the *same* soil, moisture, temperature, light, and air.
2. Use *different* proportions of sodium nitrate, potassium sulphate, and calcium acid phosphate in each plot.
3. Take the same number of random samples of the same group of seeds for each plot.
4. Have one or more plots without fertilizer for controls.

Experiments of this kind with different plants, show that on a given soil, a fertilizer rich in potash may be necessary for potatoes. Another formula with a larger percentage of phosphorus may be more favorable to the growth of corn.

During the World War, when there was urgent demand for large production, the potato growers of Maine were puzzled by a disease which devastated their crops. A government chemist showed the trouble to be due to a lack of potash. The fertilizers being used had been robbed of this substance because it was also needed in making munitions.

Unfavorable conditions for growth. Plants may fail to thrive in certain surroundings for various reasons. In homes, the air frequently is too dry. In some localities the fumes from certain factories may contain gases such as sulphur dioxide which injures the foliage. On city streets, trees often fail to thrive because the pavements prevent the proper amounts of water or air from reaching the roots. In addition, many plants constantly are subjected to the competition of other plants, and of parasitic insects or fungi.

From the foregoing statements we see that green plants utilize food for purposes of growth and reproduction. Food may be stored by the plant, largely as starch, and the length of the plant's life is related to its adaptations for such storage. Growth is related to food manufacture, which involves the presence of water, mineral compounds, favorable temperature, and sunlight. Growth represents a result of the use of energy by the organism.

SOME PLANTS ARE UNABLE TO MAKE FOOD

Some plants are not green. The problem of making a living is met by some plants in other ways than by food manufacture. Yeasts, molds, mushrooms, rusts, bacteria (a few exceptions) — fungi in general — get their energy from "ready-made" food. Some of these are parasites because they depend upon living hosts, others are saprophytes and make use of nonliving or decaying organisms. Such plants are basically dependent upon green plants for food.

Bacteria and clover. Certain bacteria are found upon the roots of a group of green plants such as clover, peas, and alfalfa.

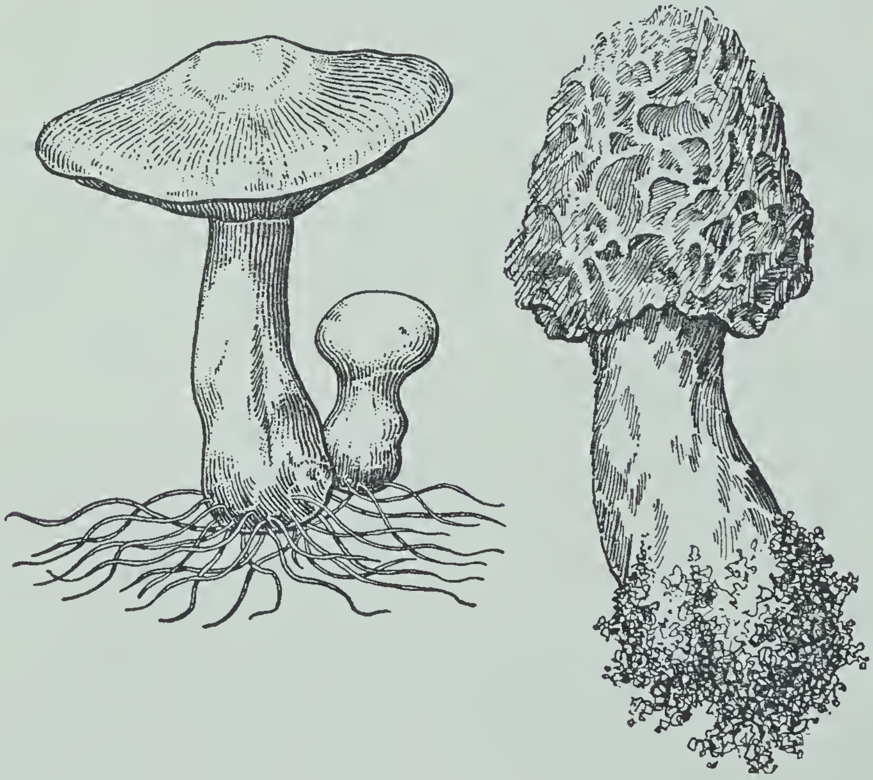

FIGURE 109. Some fungi.

For many years these crop plants have been known to be rich in nitrogen compounds, in the form of proteins. They could be made to grow upon soil which was known to be deficient in nitrates. Taking advantage of these facts, farmers often sow clover on a field and "plow it under" so that the decaying plants will restore compounds of nitrogen to the depleted soil.

Recently biologists have shown that the bacteria found on the roots of these plants (the legumes) are responsible for the production of nitrogen compounds. These bacteria not only take nourishment from the plant and the soil, but from the air absorb free (elemental) nitrogen. In the process of their own metabolism, the bacteria of this class produce nitrogen compounds, which are available for absorption by the roots of the green plants.

There are some noteworthy principles involved in this situation:

1. It is important to recall that the roots of the higher plants cannot make food, but can take in raw materials by absorption.
2. These absorbed raw materials must be in solution.
3. Nitrogen as an element is but slightly soluble, and cannot be utilized by any higher plant unless combined with other elements in the form of a nitrate compound.
4. These bacteria, in some way which is not fully understood, bring about this chemical union of nitrogen from the air with oxygen and other elements, ultimately to form nitrate compounds.

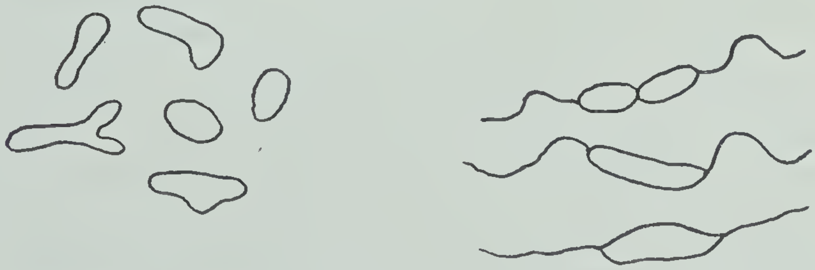

FIGURE 110. Two types of nitrogen-fixing bacteria.

Nitrogen-fixing bacteria. The name given to such bacteria is nitrogen-fixing bacteria. The name given to the process of combining free nitrogen with one or more elements is nitrogen fixation. Bacteria also have other relationships to nitrogen, as well as to plants, but here we are concerned with the nutritional relationship. We see in this association another example of two organisms — each useful to the other. In this case both are plants. The green plant furnishes carbohydrates, and perhaps proteins or fats. The bacteria take these foods for their own needs, but use part of the energy derived from them to cause the fixation of nitrogen. The nitrates are yielded by the bacteria, and are absorbed by the green plants.

Some fungi have well-organized systems for nutrition. Fungi of other kinds, such as molds, rusts, and mushrooms, develop the mycelium as a special nutritional structure. The mycelium is a device for spreading absorbing tubes (hyphæ) deep into moist material containing nutrients. Look at a piece of moldy bread. See the threads extending down into the bread. Pull off a shelf fungus from an old log and scrape away the bark around the scar on the wood. You will find threadlike structures passing down into the rotting wood. Or dig up a mushroom and look for the mycelium in the soil beneath. In all of these cases the mycelium is an adaptation for obtaining food.

Injurious and useful fungi. Molds, rusts, and mildews may be saprophytes or parasites in the same way as are bacteria. Some species are useful, and some are harmful to other organisms. Much decay of vegetables, or the plants upon which they grow, is caused by fungi of one kind or another. Rust on wheat, smut on corn, and mildew on grapes, are fungi carrying on their nutritional functions as parasites.

Decay. The decaying of dead trees or animals, including the rapid breaking down of the material into simpler chemical compounds, is accomplished largely by fungi (including bacteria). The resulting restoration to the soil of soluble food material is of great service to all other forms of life, including man. The activities of certain fungi are important in other relationships to man. We shall learn more about this subject in later discussions.

Mistletoe. Most of us know the romantic significance of the expression, "under the mistletoe." It is less well-known that mistletoe, a seed-bearing plant, is a partial parasite upon trees. The roots of the plant push their way down into the growing tissues of a tree and absorb from the tree some of the nourishment necessary for carrying on life. In the presence of such adaptations, chlorophyll and leaves are less important, and we find that the leaves of mistletoe are pale green, and rather small. Since these leaves manufacture carbohydrates and some proteins, the plant is not a complete parasite.

Dodder. Another common parasitic plant is dodder. This is completely parasitic. It has no leaves and very little chlorophyll, yet it is a flowering plant. The body consists of a slender, yellowish vine, with roots which are able to penetrate into the tissues of many plant hosts. Dodder is more common than mistletoe. It frequently grows upon goldenrod and other wild species of plants.

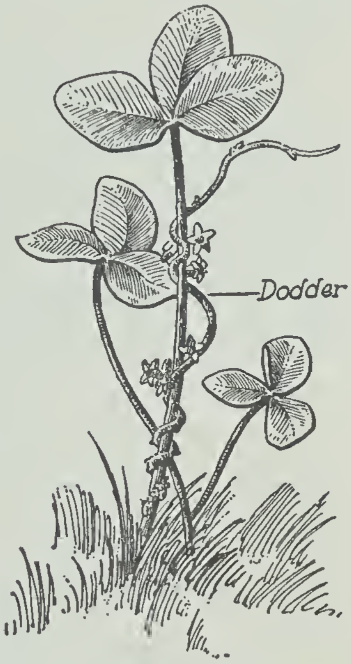

FIGURE 111. Dodder — a parasitic plant — twined around the stem of another plant.

Indian pipe. Still another flowering plant which has no chlorophyll is Indian pipe. In some cool, damp, shady part of the forest you may find some of the delicately tinted stems of these plants a few inches above the forest floor. They have no true leaves, but the stem is covered with scaly structures. The nutritional processes are roots which absorb ready-made food from organic sources.

Insect-trapping plants. Strangest of all the nutritional devices of plants are those for catching insects. Several plants possessing such structures are found in the United States. The pitcher plants have leaves rolled in the shape of pitchers. Rain water often collects in these "pitchers." Insects attracted into the bases of these "pitchers" are drowned by the water. The Venus's-flytrap is found around some fresh-water ponds. On the tips of the leaves of this species are double-bladed structures equipped with toothlike edges. When insects alight on the blades, the two halves close together, enclosing the prey. It is possible that the insects then may be dissolved and absorbed by the plant tissues, at least in part. All species such as the Venus's-flytrap and pitcher plants, however, are able to carry on their nutritional activities without using insects as food. Insect-trapping plants are green, bear seeds, and are not saprophytic. They are not true "dependent" plants.

Most plants which do not contain chlorophyll, as we have seen, must obtain food from other organisms. They may be either parasites or saprophytes. Even some seed plants are to a certain extent dependent upon other organisms for their supplies of energy.

HABITATS ARE RELATED TO METHODS OF NUTRITION

Types of plants. It has been mentioned that some members of every plant division are aquatic, some semiaquatic, and some, perhaps, are land forms. However, it also may be noted that plants of some kind are found in almost every available habitat. Mosses are found in moist places, cacti in dry places, and algæ in the water. There likewise are plants which live successfully in salt marshes, others that thrive best on acid soil, and others which are found on alkaline soils. Some thrive only when supported by another plant, or by some stationary structure. The ivies, many orchids, and so-called Spanish moss are in this latter group. Such types of plants may be grouped with reference to their habitats. For example:

1. Hydrophytes are plants which need much water.
   (Example: many algæ).
2. Mesophytes are plants which are able to live successfully with a moderate supply of water.
   (Example: elm tree).
3. Xerophytes are plants which are able to live in dry or arid regions.
   (Example: cacti).

Habitats of plants. Plant habitats are in part determined by adaptations possessed by the various species. These adaptations enable them to survive in an environment which is unsuitable for other plants. Many of such structures are concerned with nutrition. Certain structures may be unimportant in an environment where all conditions are favorable. In another environment such structures may insure survival.

Summary. In concluding this study, we may emphasize the fact that green plant cells manufacture foods. The raw materials are carbon dioxide and water. Energy for the process comes from sunlight. Such foods are made in the form of simple sugars, and converted into starch for storage in the plant body. Green plants also make fats and proteins. The foods made by green plants are utilized to provide energy and materials for growth and reproduction. These two processes are the normal result of successful nutrition, but are affected by other factors, such as extremes of temperature. We find that many plants which do not contain chlorophyll are dependent upon green plants for their food supplies. Animals are basically dependent upon green plants for food. The food-making process, then, is a means by which potential energy is supplied to all organisms. All activities of organisms represent the use of energy, which is obtained by them in the form of food.

SUGGESTED ACTIVITIES

Scientific methods

A scientist is critical of his own work, and is careful not to base general conclusions upon too few facts.

1. Perform (demonstrations) the photosynthesis experiments outlined on pages 197 and 198. Prepare a report based upon the results.
2. With the aid of a microscope, study the cross section of a leaf. (Compare what you see with Figure 107 and the description of structure on page 198.) Prepare a labeled sketch of this structure.
3. Prepare an exhibit of mushrooms, molds, rusts, mistletoe, dodder, clover roots with nodules of bacteria, and similar plant forms, as discussed on pages 207 to 210.
4. Make exhibits of numerous plants and classify them in such groups as annuals, perennials, hydrophytes, mesophytes, and xerophytes. Note the adaptations which determine the classification.
5. Man upsets the "balance in nature" by cultivating plants in a garden. Show that you understand this statement by explaining (*a*) changes in the soil resulting from the growth of a crop of vegetables,

and (*b*) the growth of weeds in cultivated areas, in competition with crop plants.

6. Plan and perform an experiment to see whether or not a plant makes carbohydrates when no carbon dioxide is in the air. Perhaps if a dish of limewater were placed beneath a bell jar the carbon dioxide would be removed from the air. Be sure to have a control.

SUMMARY OF PRINCIPLES

1. Many plants carry on their life functions in one fixed location.
2. Nutrition involves securing food, and converting it into protoplasm and energy.
3. Some of the most important and obvious structures of plants, such as roots, stems, and leaves, are adaptations for nutrition.
4. Green plants utilize the sun's energy to manufacture food from carbon dioxide and water.
5. Photosynthesis results in the production of simple sugar which is converted into starch for purposes of storage.
6. Food may be stored in roots, stems, fruits, or leaves.
7. The plant's length of life is related to its adaptations for the storage of food.
8. Some plants without chlorophyll depend upon "ready-made" food. Such plants are parasitic or saprophytic.
9. Adaptations for carrying on nutrition under unusual environmental conditions may determine the habitats of plants.

GUIDE QUESTIONS

1. In what structures of plants does photosynthesis usually occur?
2. What are the three chief parts of seed plants which are concerned with nutrition?
3. What is the chief function of leaves. Discuss four adaptations for carrying out this function.
4. Prepare a definition of photosynthesis in which you include: (*a*) raw materials, (*b*) necessary agencies, (*c*) energy source, (*d*) products.
5. What are the differences among perennials, annuals, and biennials, in terms of stored food?
6. Name four structures in which food is stored by plants.
7. What is the function of stored food in (*a*) a carrot root, and (*b*) an apple?
8. Name (*a*) two parasitic plants, (*b*) two saprophytic plants.
9. Explain "nitrogen fixation" including the following points: (*a*) source

of free nitrogen, (*b*) form of nitrogen necessary for absorption by roots, (*c*) organisms which are responsible, (*d*) relationship to crop plants.

10. What nutritional advantage, on account of body form, does ivy have in comparison with a small bush, when both are living in a thickly grown forest?

BOOKS TO READ

Chamberlain, C. J. *Elements of Plant Science.*
Gager, C. S. *General Botany.*
McDougall, W. B. *Plant Ecology.*
Parker, B. M., and Cowles, H. C. *The Book of Plants.*
Robbins, W. W. *Principles of Plant Growth.*
Weiss, F. E. *Plant Life and Its Romance.*

CHAPTER XIII

METABOLISM IN PLANTS — *continued*

Problems:

1. How are food materials obtained by the green plant, and how are these materials distributed?
2. What structures of the higher plant serve in the conduction of liquids?
3. How is growth accomplished among higher plants?
4. Do plant cells require oxygen?
5. Do plants excrete wastes?
6. How is water content regulated in the complex plant?

Foreword. In the preceding chapter we discussed the making of food by green plants, and the use of food as a source of energy and material in growth and reproduction. We shall now consider in more detail the activities carried on by various parts of the plant body.

ROOTS ABSORB WATER AND MINERAL COMPOUNDS FROM THE SOIL

Van Helmont. A Flemish physician, van Helmont (1577–1644), who became interested in plant growth, planted a willow branch in a large pot of earth, watered it regularly, and observed its growth for five years. At the beginning of the experiment the branch weighed five pounds. After five years it weighed 164 pounds. The loss in weight of the soil was two ounces. His inference was that most of the tissues of a plant are manufactured from soil water, and from raw materials taken from the air. This conclusion is verified by our experiments with photosynthesis, which indicate that carbon dioxide is obtained from the air.

Plant cells need minerals and water. In spite of the small amount of raw material furnished by the soil, the manufacture of food in leaves and other green parts of the plant would be impossible without water and the mineral substances. In the cases of most water plants and a few land plants, these materials are taken in directly through the walls of the cells. No vascular systems or root systems are present in such plants as Closterium, Spirogyra, Pleurococcus, Ulothrix, and Fucus. Most land plants, however, and especially the ferns and flowering plants, must obtain water and minerals from the soil. The adaptations for achieving this are roots for absorption, and stems for transportation.

A carrot root. Suppose we go into a garden and try to pull up a carrot. We should keep in mind that the "carrot" of commerce really is the root of the plant. At the first attempt the top may break off. The carrot seems to be firmly anchored to the ground. Next time we loosen the earth a bit with a fork or a stick. Then by a more careful pull we may succeed in bringing forth the carrot. Let us see why it held so fast. First of all, it is rather long — perhaps eight inches or more. It tapers also from one and a half inches in diameter at the top to a point at the lower end. Near the point we see a mass of rootlets projecting in all directions, to which are adhering many soil particles. At intervals along the sides are other branches which extend laterally into the soil. These rootlets tend to hold the plant firmly attached to the soil. This suggests that one function of roots is to anchor the plant.

Absorption by roots. Now let us try to find out what else this carrot root does in the soil. We place a freshly pulled carrot plant in a bottle of water colored with red ink (or eosin). It is desirable to select a bottle having a mouth just a trifle smaller than the upper diameter of the carrot and to let the carrot (root) project into the liquid two or three inches. On the following day examine the carrot plant. First we cut the root lengthwise and see that very little of the interior is colored red. Some red streaks, however, lead from the rootlets and from the tip. These pass through a layer, perhaps a half inch thick, to a region about midway between the center and the surface of the carrot root. In this region, the streaks of red extended upward, even into the stems and the leaves. Now let us put the two halves together again and cut the root crosswise, or in cross sections. We see a red ring within the carrot root. This ring represents the tissues which are concerned in the conduction of the absorbed red fluid.

Cell structure of roots. With the aid of a compound microscope we are able to see that the tissues of a carrot root consist of cells. The central portion, known as the central cylinder, is made up of soft, spongy tissue in young roots, but in older roots the cell walls of this region harden, and a fibrous, woody structure is developed. In one region of the central cylinder, the ducts which conduct liquids are located. They are composed of elongated cells, joined end to end. Around the central cylinder we find an area called the cortex. The cortex is made up of irregularly shaped parenchyma cells, containing stored food. The outer layer includes the epidermis. It is composed of cells which make up a protective covering for the root. The relative positions of these cells may be seen in the accompanying diagram.

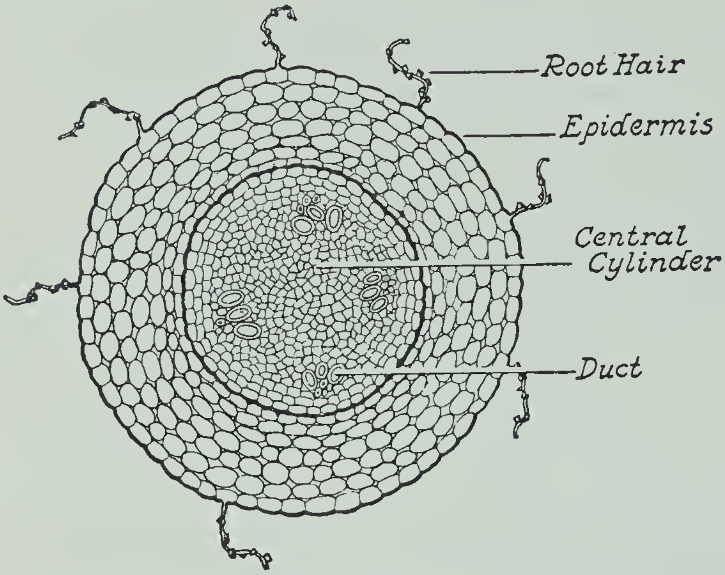

FIGURE 112. Cross section of a root (diagram).

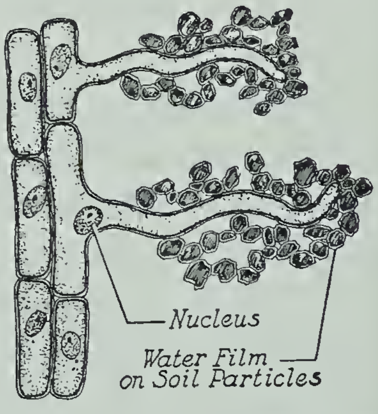

FIGURE 113. Diagram of root hairs in contact with soil particles.

Root hairs. Most remarkable of all are the root hairs. These structures illustrate the principle of cell specialization. Each root hair comes from a single cell, which develops in the epidermis, and extends its outer surface laterally into the soil. The very thin walls of root hairs permit the passage of liquids from the soil inward. The liquids are conveyed to the near-by cortex cells, and then to the ducts leading to the stems and leaves.

Chemical action. Root hairs are able to alter the material in the soil which touches them. This can be shown by simple experiment. Take an ordinary test tube, two thirds full of water. Add one drop of phenolphthalein [1] solution. Now pour in enough limewater to cause the liquid to turn a faint pink. Pull up a growing bean seedling, with a good root system, and after washing the roots insert them in the test tube containing the pink solution. Presently you will see the pink color fading and eventually it will become colorless. A "control" test tube may be set up, which contains water, phenolphthalein, and limewater, but no roots. In the case of the control, the solution will remain pink. Also, you may learn by trial that phenolphthalein is turned pink by alkaline substances, and turned colorless by acids. We may infer that the roots gave off acid substances.

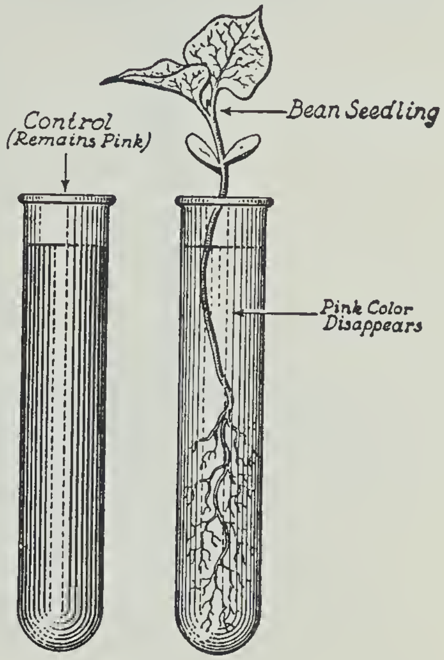

FIGURE 114. Diagram of the set-up of an experiment to show the effect of root hairs upon phenolphthalein solution. Explain the "control" in this experiment.

It appears that roots may change an alkaline soil into an acid soil. This change is brought about by secretions of root cells. The process is a sort of "digestion," which renders the soil material suitable for absorption.

Two functions performed by roots, then, are to anchor the plant to the soil, and to absorb water which contains mineral materials. Both processes are necessary to the success of the plant. The absorption of materials from the soil is a step in making food manufacture possible, and therefore is related to the use of energy.

Types of roots. The carrot root does not closely resemble in shape the roots of grasses or of common trees. There are two general types of roots: taproots, as represented in carrots, and fibrous roots, as represented in grasses. A taproot furnishes support by penetrating deep into the soil. In the case of fibrous roots, the presence of a branching structure prevents tipping of the upper portions of the plant. Young seedlings of most plants develop taproots and from these the fibrous roots or branches are formed.

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[1] May be obtained from biological supply companies, or the chemical laboratory of the school.

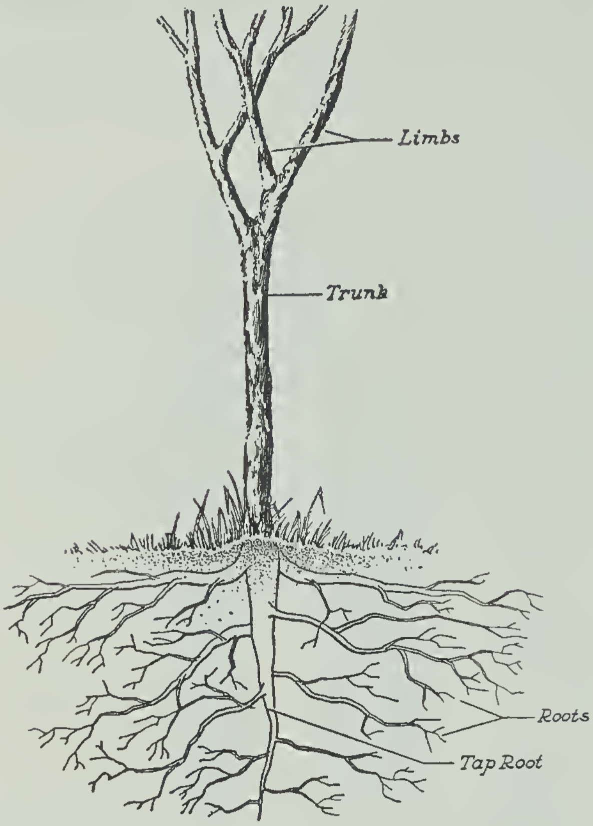

FIGURE 115. The root system of a tree (diagram).

The regions in a typical root structure (whether a main root or a branch), are essentially the same as those found in the carrot root. You will note that absorption occurs chiefly in the root hairs, and that the liquid passes through the cortex cells into the central cylinder, in which it rises through ducts.

The structure of roots. There are four general regions of a typical root:

1. The "growing point" — which consists of cells that reproduce rapidly by cell division — is not at the extreme end, but just a short distance behind the rootcap. The rootcap consists largely of dead cells, which, as they are pushed ahead, protect the growing point from direct contact with the solid particles of soil.
2. The region of elongation (including the growing point).
3. Next above is the region of root hairs. This is a region of absorption. The surface area exposed to soil solutions by the innumerable root hairs is very great.
4. Above the region of absorption, the epidermis thickens and the vascular system becomes woody.

Let us now examine more carefully some of the processes involved in the absorption of liquids by plant roots.

An experiment. Suppose we put a few dried raisins or prunes into a dish of water. At first both the raisins and the prunes probably are wrinkled and hard. After a few minutes in the water, however, the skins soften. If we leave them in the water for several hours or overnight, very likely the fruit will be swelled out nearly to the normal size of the fresh fruit. This is an example of osmosis.

Now let us set up an apparatus like that in Figure 116. Into one thistle tube (B), we put a concentrated solution of molasses or of dextrose (sugar). In the other tube (A), we put a mixture of starch and water. Both tubes are tightly covered by a membrane of parchment, or sausage casing, or some similar material. When immersed in a beaker of pure water, a change soon occurs in the tube containing the sugar solution, but not in the one containing the starch. The sugar solution rises in its tube almost at once. If the tubes are left over night, the sugar solution may rise several inches.

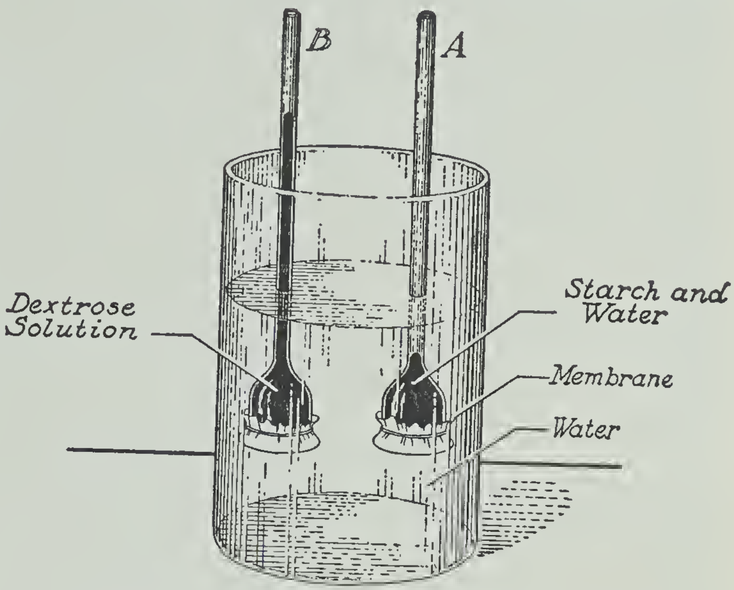

FIGURE 116. Diagram showing the use of apparatus in an osmosis experiment.

Osmosis. If we should put a cork in the open end of the tube (sugar solution) a pressure would be exerted which would cause the membrane to bulge outward. It might even force the cork from the tube. The force involved is called osmotic pressure. Osmotic pressure is developed when two solutions of different compositions are separated by a semipermeable[1] membrane. The solutions have different molecular concentrations. The molecules move, and diffusion occurs, until the solutions reach the same concentration on both sides of the membrane. Osmosis, then, is a special kind of diffusion through a semipermeable membrane. Light, small molecules diffuse faster than do large, heavy molecules. Hence, in the preceding experiment, water passes toward the sugar solution faster than sugar solution passes toward the water. Absorption and circulation within organisms depend in part at least upon osmosis. Cell membranes are more or less permeable. Certain substances pass through these membranes.

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[1] Some substances can pass through but others cannot.

Starch is not soluble in water. In the preceding experiment no osmotic pressure results when the starch suspension is separated from water by a membrane. In green plants food is stored as starch, but is used in the soluble form — sugar. Cells assimilate foods only when the latter can pass through the cell membranes — hence only when these materials are soluble in water. We now can understand that soil water and mineral salts pass into the root hairs by osmosis. This is because the concentration of the sugar materials within the cells is greater than the concentration of minerals in the soil water.

Soils. We have learned that soils contain food materials, and that these materials must be soluble if plants are to use them. Experiments also show that the texture of the soil is of great importance. The cells of the roots must have oxygen for respiration. Hence roots will not do their work unless air can reach them. This means that a porous soil favors plant growth. Water-soaked soil in flower pots is not favorable to plant growth. Many of our common trees die when their roots become permanently covered with water.

Absorption by roots. Summary. We may now bring together the main principles involved in absorption by roots. These are:

1. Raw materials taken in by the roots gain entrance to the plant body through membranes.
2. Materials must be in solution, which is more dilute than that of the cell contents.
3. The root hairs perform the function of absorption.
4. Root hairs adhere to soil particles, and secrete substances which act upon mineral salts in the adjacent soil.
5. Water and mineral salts enter the root hairs chiefly as a result of the force of osmosis.

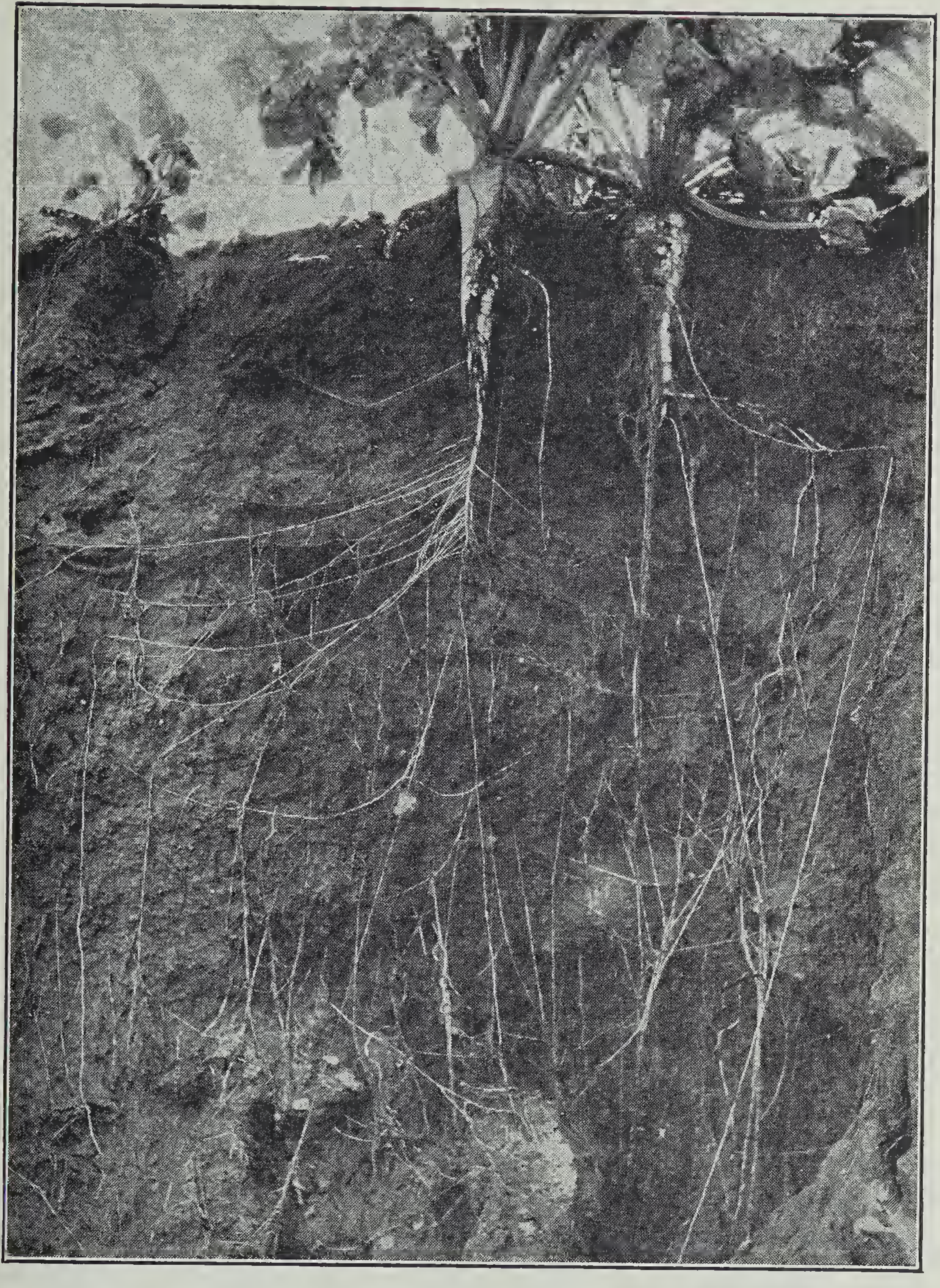


FIGURE 117. The root system of a sugar beet. (Courtesy of the U.S. Sugar Beet Association.)

6. The soil must be sufficiently porous to allow for the presence of air, which is necessary for the respiration of root cells.
7. The solutions absorbed by the root hairs pass by osmosis from cell to cell, through the cortex, and up into the stem and to the leaves through the xylem.

Root development. You may have observed that roots of upturned trees are seldom straight. Even the roots of bean seedlings or radish seedlings that you may grow in school window boxes often are bent or twisted. Why is this?

If you care to experiment with roots you can learn the answer. First, let us germinate some radish seeds in a "pocket garden." Moisten a piece of blotting paper and lay it on a small glass plate about three inches square. On the blotter scatter from five to ten radish seeds. Now place another glass plate over the seeds, put a rubber band around both plates, and set the plates up on one edge in a dish of water. The water should be about one-half inch deep.

Seedlings in a "pocket garden." If we examine the seeds in this little garden from day to day, we shall see that the seed coats burst, and little white root tips appear on the seeds. A root tip may begin to develop in any direction; upward, toward the side, or downward. But in whatever direction it starts to grow, it soon turns downward. Now we may ask ourselves what force could cause this root to turn downward. Perhaps we know that gravity is the force of attraction of the earth, which tends to pull all objects toward the earth. We may, therefore, guess that it is gravity which causes the root to turn downward. Or it may occur to us that, since water was also at the bottom of the plates, the roots were in some way attracted by the water. How are we to know?

More experiments on root growth. One way to learn is to carry out other experiments. Suppose that we investigate the theory that roots grow toward water. Let us plan some changes in the conditions of the previous experiment. First, turn the plate around so that the tips of the roots point sideways. Then empty out the water from the dish and fasten a dropping funnel full of water over the plates, so that there is a slow but constant dripping of water on the top edges. If we do this and watch the roots another day, we shall find that the roots bend again towards the earth, even though the water comes from above.

Now we may say, "Yes, it appears that gravity does affect root growth, but maybe water does also." Let us change the conditions again. For this experiment we shall need a box-shaped glass container. We put a vertical partition halfway up in the box (see Figure 118), fill both sides with soil, and keep one side wet and the other side dry. The roots of plants germinated above the partition will be observed to grow toward the side which is wet. In doing this, the roots which start downward may be found to bend sideways, but, after reaching the moist region, the roots again turn downward. We conclude that roots respond to the stimulus of gravity, and also to the stimulus of water. When water is plentiful, even though it comes from above, roots continue to grow downward. As shown by the final experiment, however, roots tend to grow toward a source of water supply.

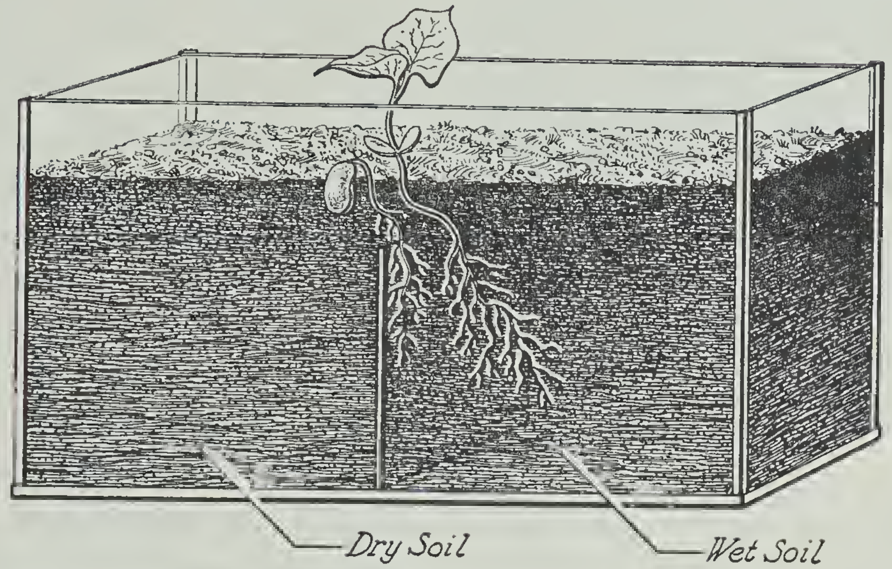


FIGURE 118. Diagram illustrating the growth of roots toward a source of water supply. What inference would you make from the observed facts?

In botanical laboratories, experiments have been made with a machine called a clinostat. Growing seedlings may be attached to this machine and turned slowly about, so that the effects of the force of gravity are counteracted by the changing position. Figure 119 indicates the result. Roots which were all pointed toward the center of the circle continue to grow in that direction when rotated.

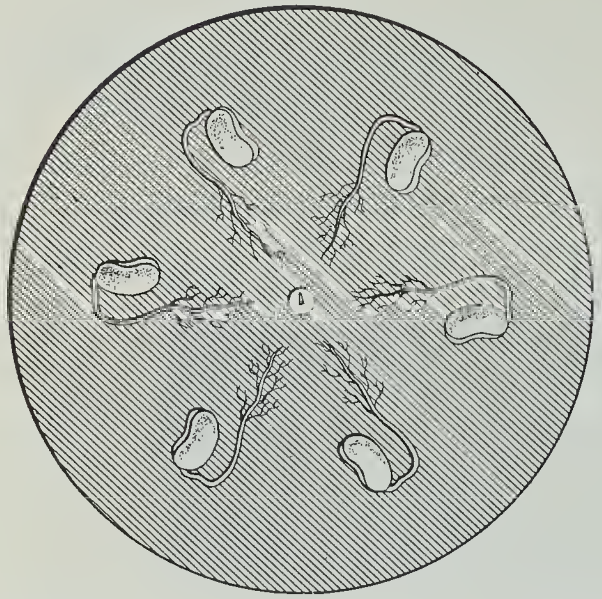


FIGURE 119. Bean seedlings, rotated slowly, continue to grow in the direction in which they started to grow before rotation. Apparently the "pull" of gravity fails to affect growth because of the constant change in position.

Stimulus and response. Neither the water nor the force of gravity "pull" the root. Rather, it seems that the living root is stimulated by the presence of water, or the force of gravity, and "responds" in its direction of growth.

The development of root systems serves the purposes previously mentioned. These are to furnish support for the plants, and also to make possible absorption of water and dissolved mineral compounds from the soil. Both, as we have seen, are involved in the general process of energy transformation.

TRANSPORTATION OF RAW MATERIALS AND FOOD IS RELATED TO THE USE OF ENERGY

Our next problem is to learn how raw materials and water are transported from roots to the leaves. We also wish to know how foods are carried from leaves to places where they are used or stored.

How do liquids move through a plant? If you cut or break a twig from a maple tree in the spring it may "bleed." Of course the liquid that flows out is not blood, but sap, which is a vital fluid of the plant. Maple trees are "tapped" for the sap from which man makes maple sugar or sirup. If you should visit a sugar camp you would find that the tap holes are bored in trees to a depth of one or two inches. The sap appears to exude from a region a short distance beneath the bark.

Experiments with stems. To see how liquids rise, insert the ends of several young growing stems, willow for example, into some water colored with red ink. After a few days, cut the stems in various ways, making longitudinal sections and cross sections at several points. It will be found that the liquid rises in the xylem layer. Examination of the section of the stem with the aid of a lens will reveal that the cells of xylem tissue are organized for purposes of conduction. Tubes formed from strings of cells, whose end walls have been dissolved away, make a continuous "pipe line" from roots to leaves. Such tubes are called ducts. Other tubes in the same tissue called tracheids consist of elongated single cells. Both the tracheids and the ducts serve as carriers of liquids which move upward, or away from the region of the roots.

Xylem and phloem. Outside of the xylem is an actively growing layer called the cambium. The phloem forms another layer outside of and next to the cambium. Phloem tissue transports food materials. It may be shown experimentally that on a willow, for example, few if any roots will start to grow below a "girdle." A girdle is made by cutting off a ring of bark, phloem, and cambium, near the lower end of a young, growing stem. When this is done thoroughly and the cut end is placed in water for a few weeks, roots appear above the girdle but not below. How do you explain this? If a young tree is girdled through the cambium layer it will soon die. Girdling was practiced by the Indians in colonial days to kill trees, and thus to assist in letting sunlight reach their fields of growing corn.

Translocation. Botanists use the word translocation to refer to the movement of food from leaves to storage, and from storage to the various cells of the plant body. All of the cells need food, water, and oxygen. Oxygen reaches the interior of the plant by way of the stomata and the intercellular spaces. Liquids pass up and down the stem, and this movement represents conduction rather than circulation because the pathways do not constitute a circuit. "Translocation" is more descriptive than is "circulation."

Movement of liquids in plants. The forces that assist in the movements of water and the translocation of food in plants probably are several. Botanists used to explain the rise of sap almost entirely under the term "root pressure." Osmosis does account in part for the movements of water and soluble compounds into and out of cells. It may account for some movement of liquids in stems. However, other forces probably are involved.

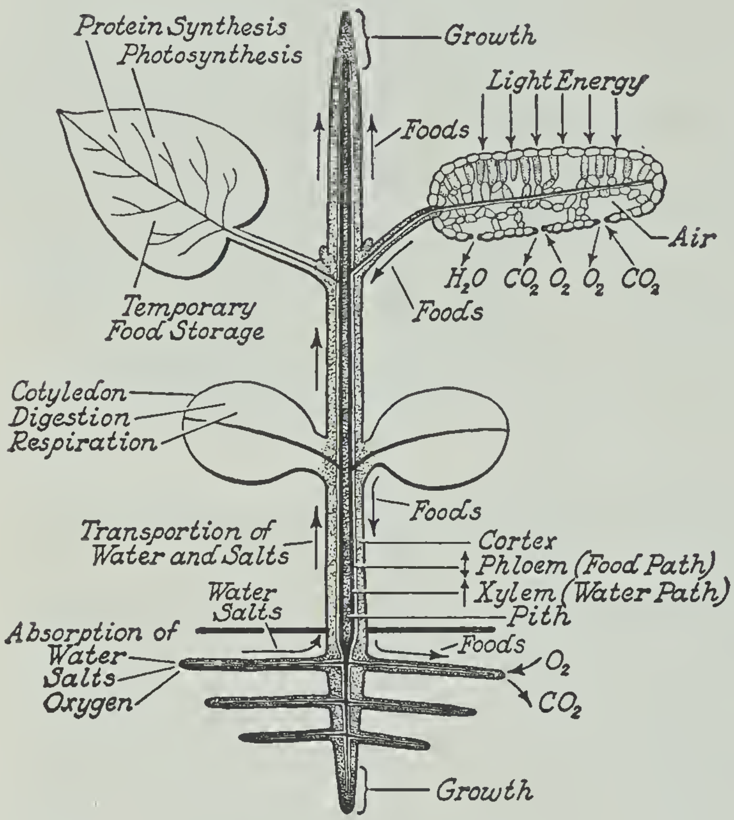


FIGURE 120. Diagram showing the arrangement of tissues in a higher plant.

Rise of liquids in tubes. If you hold one corner of a blotter in some red ink you will find that the ink rises and colors the blotter far above the level of the liquid in the dish. The resemblance to the rising of ink in the willow twig is apparent. In fact the same forces are at work in both cases. There are very fine tubes and intercellular spaces in a stem, as well as in the blotter. Such minute tubes are called capillaries, and the force which causes liquids to rise in these spaces is called capillarity, or capillary attraction. This force, in turn, is due to the molecular attraction (adhesion) of the liquid to the inner surfaces of the tubes. Experiments show that the finer the tubes, the higher water will rise in them. Some of the tubes and ducts in plant stems are so fine as to be distinguishable only with a compound microscope. It is apparent that water might be raised to a considerable distance in them by the forces of capillarity.

The forces of osmosis and capillarity account for some of the movements of liquids in plants. Yet these forces are kept in operation by other processes, which dispose of the water and hence create a demand for more.

Importance of transportation. The transportation of raw materials and foods is of greatest importance in the life activities of the green plant. Raw materials are made available to chlorenchyma cells (largely in the leaves). Foods are transported to the various cells of the plant body, are assimilated, and become the basis for growth, and for release of energy that is used in metabolism.

Conducting systems. As we have seen (see page 225), liquids are conducted to and from the roots and leaves by special tissues. These conducting tissues comprise the framework of the stems. Since they are both tubular and fibrous they are known as fibrovascular bundles. In leaves the fibrovascular bundles are represented by the structures known as veins.

Fibrovascular bundles may be seen when the stem of a young dicot plant is examined. If a very thin cross section of such a stem — a young sunflower stem for example — is viewed under a compound microscope, it will appear much like the diagram in Figure 103. The outer portion of each bundle shows the ends of the tubes known as phloem tissue, in which food materials pass downward from the leaves. The inner vessels are known as the xylem tissue. Between the phloem and the xylem is the region called the cambium.

GROWTH RESULTS FROM ASSIMILATION

What is growth? Growth is the general name for the formation of a larger body. A bean seedling in a warm place, with water, light, air, and in a soil supplying adequate mineral salts, grows measurably for several weeks. This is the result of use of foods, and of energy that is liberated in oxidation.

Regions of growth. If you have ever made a willow whistle or chewed the bark of black birch in the spring, you know that a green, juicy tissue lies close to the surface in young twigs. This soft layer in a growing dicot stem is in part the cambium. Here the cells multiply rapidly to form the xylem on the inside and phloem on the outside. Each year, as the diameter of the stem increases, the cambium is farther from the center. As the stem increases in diameter the bark may become cracked, and pieces of bark may fall off from time to time. Access to the interior of the stem is provided by openings called lenticels. Lenticels may be seen as distinct markings on cherry, birch, and many other common trees. Any plant tissue in which growth is occurring by cell division is called meristem tissue. Root tips, buds, and cambium are meristem tissues.

Buds. New growth of stems, leaves, or flowers is preceded by formation of buds. On each terminal branch, and in the axils of the leaves may be seen, in miniature, the structures to be developed during the next growing season. Buds form at the ends of fibrovascular bundles. Each bud and the structure into which it develops thus is connected to the transportation system and so to the root system. In Figure 120 it can be seen that the fibrovascular bundles extend from the roots to the structures developed by the stem.

Medullary rays. The pith is a soft tissue which occupies a large part of the space in monocot stems and in green stems generally. In older dicot stems, this pith remains about the same diameter as that which develops the first year. In the wood there remain areas of thin-walled cells which in the cross section radiate from the center and are called medullary rays. The pith is a sort of storehouse for food. The rays serve in this capacity and as a means of transportation of food materials and gases between the interior and exterior of the stem. As we have seen, the lenticels give access to gases from the exterior.

Stems as supports. Perhaps the most obvious function of stems is that of providing support for the leaves and reproductive structures. Vines, most of whose stems are nonrigid, succeed in obtaining their needed light and air by growing upon other plants. Adaptations, such as tendrils of a grape, twining habits of honeysuckle, or aërial roots of the English ivy, are familiar to most of us.

Grasses and dandelions are common short-stemmed plants. While they are successful in some regions, they do not thrive in the forest, in competition with long-stemmed plants. Other adaptations may give such plants certain advantages which make up for their lack of long stems. Dandelions, for example, have rather long taproots, and can get moisture or retain it when other small plants fail to do so. They also have spreading leaf rosettes which are resistant to cold, and food is stored in their root systems. These factors enable them to start growth early in the spring, and complete their reproductive cycle before many other plants have resumed full activity. Arbutus, while a short-stemmed plant, thrives in the forest because of adaptations for flowering early in the spring, before leaves on the trees have shaded the ground.

Underground stems. The familiar white potato is not a root, but an underground stem or tuber. There is no absorption of materials from the soil by potatoes, nor are they necessary for anchoring the plant. Each "eye" of a potato is a bud, which sprouts readily when the potato is stored in a warm place. These "eyes" furnish a means of propagation, which is taken advantage of by potato growers. "Seed" for potato crops is made up largely of pieces of potatoes, cut so that each piece contains one or more "eyes." Grasses, ferns, and many other short-stemmed plants have widespreading, fibrous systems of underground stems, which form buds at frequent intervals. Such underground stems are adaptations which make possible rapid production of new plants. No doubt this in part offsets any disadvantages which result from the fact that these plants have short stems.

Growth in general. In concluding our study of growth in the green plant, we may again note that growth here means increase in size. Roots, stems, and other structures of plant bodies may grow. In previous studies, we have learned that growth in a complex body depends upon increase in the number of cells. The chlorenchyma cells of green plants make foods, which are assimilated by cells of the plant body. These cells are thus enabled to carry on oxidation and release energy for work. Energy is required for the work of cell division, and food materials must be available for the growth and repair of new cells. Thus the use of energy is intimately associated with growth.

OXIDATION RELEASES ENERGY IN THE CELL

Respiration in plants. All active plant cells need oxygen. The oxygen is necessary for oxidation of chemical compounds in protoplasm, such as sugars, fats, and proteins. This oxidation, as we have seen, releases energy for work. Oxygen reaches the cells of the plant in water solution, and not as a free gas. It passes through the cell membranes by diffusion. Thus we see that respiration in the plant involves the oxidation of materials, and the release of energy.

Photosynthesis and respiration. In the process of food making or photosynthesis, the green plant makes food compounds which contain potential energy. In respiration (which includes oxidation) the food compounds, such as glucose, are broken down into the substances from which they were formed, and energy is released. A comparison of these facts may be seen in the following equations:

Photosynthesis:

$$6\ CO_2 + 6\ H_2O + \text{energy} \longrightarrow C_6H_{12}O_6 + 6\ O_2$$

(carbon dioxide plus water yields glucose and oxygen)

Oxidation (involved in respiration):

$$C_6H_{12}O_6 + 6\ O_2 \longrightarrow 6\ CO_2 + 6\ H_2O + \text{energy}$$

(glucose plus oxygen yields carbon dioxide and water)

Of these two processes, animals carry on only respiration; green plants carry on both, although photosynthesis occurs only in the presence of light. You must carefully distinguish between them. Respiration is a life function of every living cell.

Misunderstanding sometimes arises because both of these processes, in green plants, occur in the leaf, and at the same time. Yet respiration also occurs in all the living cells of the stem, roots, flowers, and fruit. Photosynthesis occurs only in the green chlorenchyma cells, which often are almost entirely in the leaves.

EXCRETION OCCURS IN GREEN PLANTS

Whenever cells are active we may expect waste products to be formed. The discharge or disposal of such waste products becomes part of the story of how energy is used by the organism.

Excretion in plants. It sometimes is asked whether or not plants carry on the function of excretion. The answer is, of course, that all living cells of the plant do excrete certain products of metabolism. The carbon dioxide resulting from oxidation may pass out into the air, or it may be used by the green cells. Plants also lose water vapor. Other products of the plant's metabolism may appear as secretions, such as gums and resins.

MANY HIGHER PLANTS LOSE WATER VAPOR BY TRANSPIRATION

Water is used in photosynthesis. We have learned that water is used in photosynthesis. It has been calculated that for every pound of simple sugar made by a plant, a little more than half a pound of water is needed as raw material. In a higher plant this means that a large amount of water must be supplied to the leaves. When plenty of water is supplied to the roots of plants, there is a difference in the amount of food manufactured. For example, in certain experiments conducted in Utah, one acre of corn without artificial watering produced twenty-six bushels. Another acre of the same kind of corn, growing on similar soil during the same season, produced fifty-two bushels. In the latter case the soil had been irrigated. Other experiments show that of all the water absorbed by roots, less than one per cent is used in photosynthesis.

Transpiration. Let us see what becomes of this water. First we set up an experiment like that pictured in Figure 121. We may use any thrifty potted plant, such as a geranium. A rubber sheet should be tied close about the stem of the plant and over the

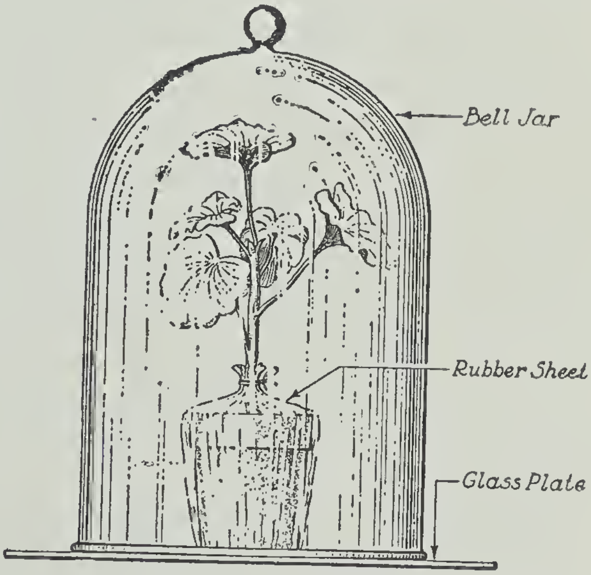


FIGURE 121. Diagram showing the apparatus used in a transpiration experiment.

entire pot. This will prevent any water from coming out of the soil or the porous pot. The bell jar which covers the plant should be set on a glass plate greased with a little vaseline. If the plant is well-watered before the experiment, and then placed in a well-lighted spot, moisture will begin to cloud the inside of the bell jar very quickly. In a few hours the inside of the glass will probably be covered with a heavy coating of water.

Obviously this water must have come from the leaves and stems of the plant. The process by means of which a plant gives off water in this way is called transpiration.

Rate of transpiration. If the same plant, together with the pot, soil, and rubber sheet, but without the bell jar, is weighed at the beginning of the experiment and thereafter at intervals, measurements of the amount of water transpired can be made. The rubber sheeting can be lifted to add water and air, and the experiment may be conducted over a period of a week if desired. The approximate amount of water lost by transpiration may be estimated by subtracting the final weight of the plant, pot, soil, and rubber sheet from the sum of their original weights plus the weight of water that has been added from time to time.

Gardeners estimate that greenhouse plants lose on the average 720 grams of water every twenty-four hours for every square meter of leaf area. Under outdoor conditions, in the summer, even greater amounts may be transpired. Thus a common maple tree twenty-five feet in height might have a leaf area which would transpire one hundred pounds of water per day, or several tons during one summer season. It is an interesting fact that a forest may give off more moisture by transpiration than an equal area of water in the same region would yield by simple evaporation.

Evaporation. The conditions which favor evaporation, however, also favor transpiration. And the rate of evaporation, as we learn in physics, may be increased by four factors: (1) increase of surface area, (2) increase of temperature, (3) movement of air over the surface (e.g. winds), (4) decrease of vapor in the air. Thus on hot, dry, windy days, we would expect transpiration to be greatest from a given area of leaf surface. But transpiration is not exactly the same as evaporation; transpiration is influenced by several conditions within the plant.

Turgor. Transpiration takes place through the stomata, and is regulated by the position of the guard cells. These guard cells are affected by the water content of the near-by chlorenchyma tissue. When water is plentiful in this tissue, the stomata open. This condition, in which the plant cells are bulging with abundant water, is known as turgor. It is the healthy, vigorous condition of active metabolism. The crispness of lettuce and celery and the freshness of flowers are evidences of turgor. Turgor represents osmotic pressure within the cells. It is affected by the water supply in the vascular system of the stems, and by osmosis in the root hairs which absorb abundant soil water. When flowers or celery wilt, they are said to be flaccid (the opposite of turgid).

Summary. In summarizing, we see that one important function of roots is to absorb water from the soil. The water contains mineral compounds that are in solution. It is absorbed by the root hairs and then passes through other cells to the xylem, by which it is conducted through the stem to the leaves. Water and mineral compounds are necessary in the process of food manufacture. In addition to absorbing water, roots anchor plants to the soil. After raw materials have been absorbed by roots, they are transported to the chlorenchyma cells (leaves). Food manufactured by chlorenchyma cells is transported to active cells of the plant body. Foods are assimilated by the cells, and are used in growth and repair. As part of the cell protoplasm, foods also are oxidized to supply energy for carrying on life activities.

The process of respiration makes possible oxidation in the cells, and the release of energy for work. When food compounds in protoplasm are oxidized, waste products, such as water and carbon dioxide, are formed. In the green plant these substances may be used by the chlorenchyma cells in food manufacture, or they may be discharged. In many plants loss of water vapor takes the form of transpiration. The great bulk of water absorbed by the roots is discharged in this way. Water vapor passes out through the stomata of the leaves. Oxidation must occur if energy is to be released in the cells, and excess waste products that result from oxidation are discharged by the cells.

SUGGESTED ACTIVITIES

Scientific methods

A scientist makes use of some basis of comparison (a control), to measure differences which appear in experiments.

1. Using a carrot root, perform the experiments testing absorption of liquids, as outlined on pages 215 and 216.
2. With the aid of a microscope, examine a section of a root which shows root hairs. (Use a permanent mount.) Prepare a sketch showing the relationship of the root hairs to the root.
3. If a bean seedling and other materials are available, perform the experiment outlined on page 217.
4. With the aid of a microscope, examine a longitudinal section of a root tip. Identify four general regions, as described on page 218.
5. If materials are available, perform the osmosis experiments outlined on pages 218 and 219.
6. Perform experiments to test factors which may affect root growth and development, as suggested on pages 222 and 223.
7. Perform the experiment involving the rise of liquids in stems, as outlined on page 225.
8. Perform experiments and report some facts concerning the growth of stems when girdled, or when injured in a particular spot, or when branches have been broken off.
9. If the cross sections of monocot and dicot stems have not been studied, as suggested on page 182, make such a study, with special reference to the fibrovascular bundles.
10. Perform the transpiration experiment as outlined on pages 231 and 232.
11. Testing exercise. On a sheet of paper make an outline A 1 2 3 and B 1 2 3 like that given below. Select the term in column 2 which best fits each description in column 1. Write the term after the corresponding number on your answer paper.

Column 1	*Column 2*
A.	
1. Contain chromatin	chloroplastids
2. Contain chlorophyll	nuclei
3. Contain cellulose	cell walls of plants
	contractile vacuoles
	pyrenoids

B.

Column 1

1. Releases energy from foods
2. Is a common solution medium
3. Furnishes energy for photosynthesis

Column 2

water
nitrogen
sunlight
oxidation
carbon dioxide

SUMMARY OF PRINCIPLES

1. Roots furnish support for plants and absorb water containing dissolved mineral compounds from the soil.
2. Liquids are absorbed from the soil by specialized structures called root hairs.
3. The growth and development of roots is influenced by gravity and by sources of water supply.
4. Water absorbed by roots is transported by xylem tissue. The rise of water in stems probably involves osmosis, capillarity, and other processes which dispose of water and create a demand for more.
5. Phloem tissue conducts food materials.
6. The assimilation of food is the basis for growth and the use of energy.
7. The cambium is an actively growing layer in the dicot stem.
8. Buds give rise to stems, leaves, or flowers.
9. Plants carry on respiration, which involves oxidation and the release of energy from food compounds in the plant. All living cells of the plant body perform this function.
10. Plants excrete certain waste products.
11. Liberation of water vapor from leaves represents the process of transpiration.
12. Absorption of raw materials, food manufacture, transportation, oxidation, excretion, and transpiration are processes involved in the use of energy by green plants.

GUIDE QUESTIONS

Roots:

1. Name the regions of a typical root.
2. Name two adaptations of root hairs for absorption.
3. What adaptation prevents injury to the growing part of a root?
4. In respect to the absorption of raw materials by roots:
    a. State the kinds of raw materials absorbed.
    b. State the name of the process.

  c. Must the raw material be soluble or insoluble?
  d. What relative concentration of liquids inside and outside the root are necessary for absorption?
  e. What structures carry on the absorption?

5. Draw a sketch of the cross section of a carrot root in the region of root hairs. Label the essential structures.
6. Describe the two main functions of roots. What are two types of roots?

Stems:

7. What are two functions of stems? What are two types of stems?
8. Why is "translocation" a better word than "circulation" for describing the movement of liquids in plants?
9. In what tissues of stems would liquids more commonly: (*a*) pass upward, (*b*) pass downward?
10. What are two physical processes which are in part responsible for movement of liquids in plants?

General:

11. What are four conditions favorable to the growth of plants?
12. What are the growing regions of a common flowering plant?
13. What is the significance of a wide, and of a narrow annual ring, in the cross section of a tree?
14. What is meant by potential energy?
15. What is the name of the chemical process by which energy is released from food?
16. Write the chemical equation in words or in symbols for: (*a*) photosynthesis, (*b*) respiration.
17. Distinguish transpiration from evaporation.
18. Which yields to the air more moisture under the same conditions, a forest, or a lake of the same area?
19. What is the meaning of "turgor"?

BOOKS TO READ

Gager, C. S. *General Botany.*
Osterhout, W. J. V. *Experiments with Plants.*
Robbins, W. W. *Principles of Plant Growth.*
Transeau, E. N. *General Botany.*

CHAPTER XIV

NUTRITION IN ANIMALS

Problems:

1. From what sources do animals obtain food?
2. How is food utilized in the human body?
3. What factors are essential to good nutrition?
4. What important diseases involve the digestive system?

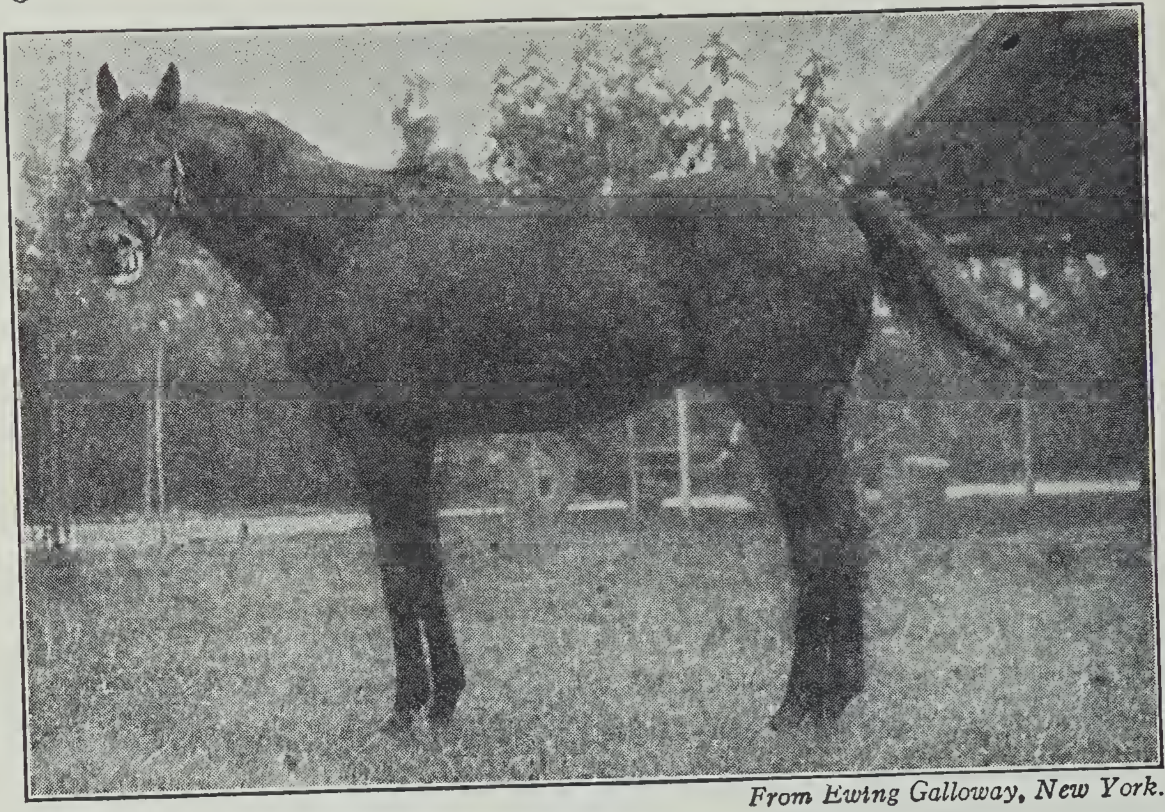
Foreword. We have learned that the activities of all organisms represent energy changes. The green plant obtains energy directly from sunlight, and this energy is used in the manufacture of foods. In the case of animals, food containing potential energy is eaten, digested, and absorbed. Nutrition is of such great importance because it is the first step in supplying the stream of energy which makes possible all phases of plant and animal activity.

ANIMALS DIFFER AS TO FOOD HABITS

In our earlier studies of the inhabitants of a fresh-water pond, we learned that different species of animals often eat different kinds of foods. This is why food relationships in a community of organisms often are so complicated. It is not always a case of the "big ones eating the little ones." Consider, for instance, the tiny, parasitic organism which consumes the tissues of a large animal.

It is difficult to classify many kinds of animals upon the basis of food habits. However, in addition to the parasitic types, three general groupings may be suggested. These include the herbivors, the carnivors, and the omnivors.

Herbivorous animals. Animals such as cows, horses, sheep, and rabbits feed largely or entirely upon plant materials. These animals are said to be herbivorous, which is another way of saying that they are plant eaters.



From Ewing Galloway, New York.

FIGURE 122A. A horse — an example of a herbivorous animal. Would you expect a horse or a lion to have the longer food canal in proportion to its body length?

Carnivorous animals. Tigers, lions, minks, wolves, and similar species feed largely upon the flesh of animals that they may succeed in killing. Such flesh eaters are said to be carnivorous.

Omnivorous animals. Some animals feed upon both flesh and plant materials. The common house rat, for instance, eats a wide variety of foods, including materials of plant and animal origin. The same is true of the house mouse, and to a lesser extent, of the domesticated pig. Such animals as these are said to be omnivorous in food habits.

Man probably should be classified as an omnivorous animal because of the wide variety of plants and animals that he uses as food. Incidentally, it probably is advantageous for a species to be omnivorous. Such a species is likely to find food in many places and under a wide variety of conditions. We find that some of these omnivorous types are among the most successful kinds of animals.

From Ewing Galloway, New York.

FIGURE 122B. A group of lions feeding upon a victim. What name is given to an animal which lives largely or wholly upon flesh?

DIGESTION IN THE HUMAN BODY

(Digestion precedes absorption; complex foods are broken down into simpler, component parts)

Digestion refers to the breaking down of complex foods into more simple substances which are soluble and may be absorbed by the blood. To a certain extent this process may be mechanical, involving the breaking up of the larger bits of food into smaller pieces. But perhaps the more important phase of digestion involves the chemical actions of the digestive enzymes.

Digestive system. The digestive canal of the vertebrate is a tube extending through the body. Certain areas of this canal are specialized and perform definite functions. In man (see Figure 123) we recognize such areas as the mouth, the pharynx, the œsophagus, the stomach, the small intestine and the large intestine, the latter terminating with the anal opening. The salivary glands, pancreas, and liver are associated with the digestive canal, and connected to it by means of ducts.

Structure of the digestive canal varies somewhat among the different species of vertebrates. Generally speaking, the digestive canals of herbivorous animals are much longer than those of carnivorous animals. This is necessary because such plant foods as grasses and leaves contain less nourishment per unit of bulk than does meat. The added length of the digestive canal is achieved by looping and folding of the intestine within the body cavity.

In man we recognize three divisions of the small intestine. The first (anterior) is the duodenum; then follow the jejunum and the ileum. The ileum unites with the large intestine, but at the point of union there is a blind pouch or extension of the large intestine called the cæcum. This cæcum bears a smaller, fingerlike pouch known as the appendix.

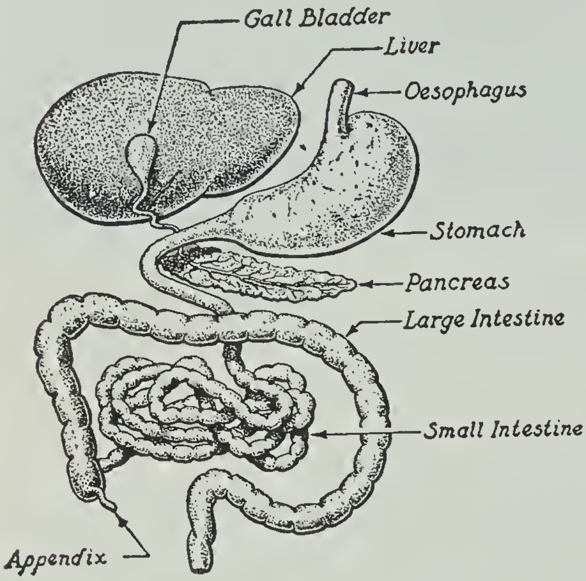


FIGURE 123. Diagram of the human digestive system.

Digestion in the mouth (man). Digestion in the mouth is partly mechanical and partly chemical. The mechanical phase is known as mastication, which is the process whereby the food is broken up between the teeth and mixed with the saliva which enters the mouth cavity from the salivary glands. The tongue plays an important rôle in moving the food about within the mouth.

The normal adult human being has from twenty-eight to thirty-two teeth. Across the front of the mouth are four chisel-like incisor teeth in the upper jaw and a like number in the lower jaw. Bordering each side of the incisors, above and below, is a single, somewhat pointed, canine tooth, making four canines in all. The remaining teeth are premolars and molars, and have grinding surfaces. They are distinguished by the fact that premolars appear in the so-called "milk teeth," and molars appear only in the "permanent" teeth. There are two premolars on each side of each jaw, making a total of eight. Variation occurs in the case of the molars, there being from two to three on each side of the jaw, and the total being from eight to twelve. Third molars sometimes are known as "wisdom teeth." In the adult, the back teeth may exert a pressure of some 270 pounds upon the food.

Human saliva is produced by three pairs of salivary glands. In some vertebrates the saliva contains no known chemical agent, but in man it contains the enzyme ptyalin. Ptyalin begins the digestion of carbohydrates by converting starch into sugar. The activity of ptyalin is not limited to the mouth; it continues to be active for some time after the food has reached the stomach.

The œsophagus (man). From the mouth the food passes into the pharynx, which might be called the back of the mouth, and then into the œsophagus. The œsophagus extends down through the neck region and the upper part of the body cavity or thorax. Then it passes through the diaphragm, the muscular division between the thorax and the lower part of the body cavity or abdomen, and joins the anterior end of the stomach.

Food is forced down the œsophagus by traveling waves of muscular contraction which move from the anterior end of the œsophagus toward the stomach, forcing the food before them.

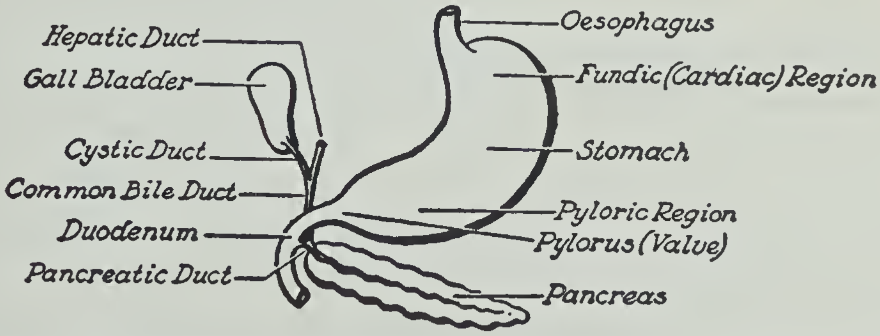


FIGURE 124. Diagram of the human stomach and associated structures.

The human stomach. The anterior region of the stomach is known as the fundus. Its muscular walls exert a steady pressure upon the food, tending to force it down into the posterior end of the stomach, known as the pyloric stomach. The posterior end of the stomach is guarded by a ring of muscle tissue, the pyloric valve. Regulated by chemical action, this valve opens from time to time to allow small quantities of food to pass into the duodenum.

Reference has been made to the steady contraction of the fundus upon the food. In the walls of the pyloric stomach the contractions take the form of a series of waves of contraction, known as peristalsis. These waves of contraction mix the food with the gastric juice and force it onward toward the pyloric valve. When the stomach has been empty for some time the walls of the fundus contract sharply to produce the "pangs of hunger." Strange to say, if no food is eaten these contractions will cease after a period of about two or three days.

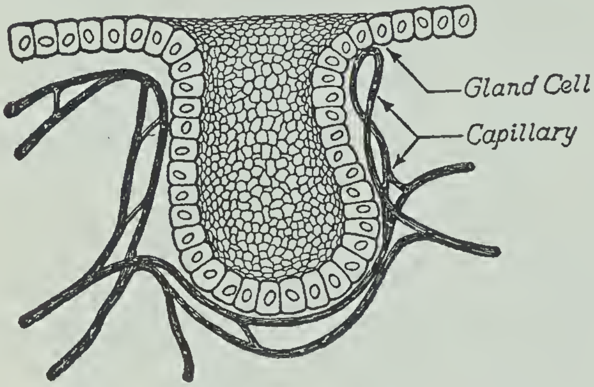


FIGURE 125. Diagram of a gland. How does food material get to these cells? How do they discharge their secretion?

The gastric juice of the human stomach is the product of the gastric glands which line the interior of that organ. Gastric juice contains three enzymes. Pepsin is an enzyme which begins the digestion of proteins, breaking them down into proteoses and peptones, which are not absorbed but pass on into the small intestine. Rennin is an enzyme which acts upon soluble protein of milk, causing it to become insoluble in the form of curds. The curds then are acted upon by pepsin. Gastric lipase is an enzyme of the stomach which has a limited action upon fats, breaking them down into glycerine and fatty acids.

In addition to the enzymes, gastric juice contains hydrochloric acid. This acid serves several functions, among which may be mentioned the following: (1) it coagulates some proteins, (2) it assists certain enzymes in changing complex carbohydrates to simple sugars, (3) it destroys certain bacteria present in the food, and (4) it provides a necessary chemical condition (acid), for the action of pepsin. An artificial gastric juice can be made by adding 2 grams of powdered pepsin to 100 cc. of .4 per cent hydrochloric acid.

Digestion in the stomach is particularly important in that connective tissue which encloses nutrients is broken down. Altogether, as a result of the combined action of water, gastric juice, and peristalsis, the food materials are reduced in the stomach to a soft mass. This mass, called chyme, has an acid reaction.

Digestion in the human intestine. At intervals the pyloric valve opens and allows chyme to pass into the small intestine. After the food has entered the intestine, it moves along at the rate of about an inch a minute, due to waves of contraction in the intestinal wall. There also are contractions which do not force the food along, and these are known as rhythmic contractions. Rhythmic contractions compress and mix the food in the intestine.

The enzymes of the pancreas are discharged into the duodenum by way of the pancreatic duct (or ducts, since in addition to the main pancreatic duct, there may be a smaller accessory pancreatic duct in the case of man). The common bile duct, conveying bile from the liver, often unites with the main pancreatic duct and the two discharge into the duodenum through a common opening.

The pancreatic juice contains three enzymes. The enzyme trypsin acts upon proteins, tending to break them down into amino acids. Lipase, like gastric lipase, tends to break down fats into glycerine and fatty acids. Amylopsin continues the digestion of carbohydrates.

The intestinal fluid (sometimes called the "intestinal juice"), secreted by glands in the walls of the small intestine, contains four enzymes. The enzyme erepsin breaks down proteoses and peptones (which are proteins) into amino acids. The three inverting enzymes (maltase, sucrase, and lactase) complete the digestion of carbohydrates, which are reduced to simple sugars.

The bile secreted by the liver, and reaching the small intestine by way of the common bile duct, is probably more of a waste

Table II. Enzymes and Their Actions (Man)

Enzyme	Source	Action on	End Products
Ptyalin	salivary glands	carbohydrates	sugar
Rennin	gastric glands	soluble proteins of milk	insoluble proteins
Pepsin	gastric glands	proteins	proteoses and peptones
Gastric lipase	gastric glands	fats	glycerine and fatty acids
Amylopsin	pancreas	carbohydrates	sugars
Trypsin	pancreas	proteins, (peptones)	amino acids
Lipase	pancreas	fats	glycerine and fatty acids
Erepsin	intestinal fluid	proteins	amino acids
Inverting	intestinal fluid	carbohydrates	simple sugars

product than it is a digestive fluid. Its presence in the small intestine favors the digestion and absorption of fats.

In general, chemical conditions in the intestine are alkaline. There is some acid present, coming from the gastric juice which enters the intestine from the stomach. The fermentation of sugar and the digestion of fat in the intestine result in the formation of some acid compounds.

The digestion of foods represents the first step in the use of foods by the animal body. The foods are first rendered soluble, after which it becomes possible for them to be absorbed into the blood stream, and transported to the many cells in different parts of the body.

ABSORPTION IN THE HUMAN BODY

(In the human body most absorption occurs in the region of the small intestine)

Absorption (man). In man the absorption of food takes place largely in the region of the small intestine. The inner surface of the small intestine is folded and bears many small projections known as villi. The villi increase the area available for purposes of digestion and absorption. The wall of the small intestine also contains many branched endings of blood vessels, and the lymph vessels known as lacteals. Digested food enters the circulation through these channels.

Alcohol and such substances as pepper and mustard may be absorbed in the region of the stomach, but little or no proteins, fats, and carbohydrates are absorbed before they reach the small intestine. A good deal of water is absorbed in the region of the large intestine.

Proteins are absorbed after having been broken down into amino acids. Fats are absorbed in the form of glycerine and fatty acids. Carbohydrates are absorbed as simple sugars.

The next step in the use of foods is a function of the circulatory system. It is the transportation of absorbed food materials, and distribution of these materials to the cells of the body. Here is a case wherein the functions of the digestive and the circulatory systems are related. As we study the use of energy in the animal body we shall see that other systems also are involved.

VITAMINS ARE ESSENTIAL TO GROWTH AND HEALTH

Vitamins. What we refer to as vitamins are known to be essential to the normal metabolism and well-being of man and some other vertebrates. Our knowledge of vitamins depends largely upon observation of the diseases which appear when they are absent from the diet. The diseases referred to are known collectively as deficiency diseases.

Vitamin C. Scurvy is a disease that formerly was common among sailors in the days when ocean voyages were lengthy, and the passengers and crews had little opportunity to obtain fresh foods. Soreness of the gums and decay of the teeth are common features of this disease. It develops when there is lack of vitamin C, which is present in many fresh foods; for example, limes, lemons, fresh potatoes, fresh meat, oranges, and tomatoes. Recently there has been much interest in the possible relationship of vitamin C to the proper development and preservation of the teeth. Of course, the teeth are likely to suffer in cases of scurvy.

Vitamin D. Rickets is another well-known deficiency disease, which develops when the calcium-phosphorus balance in the blood is not normal, but can be prevented by the inclusion in the diet of vitamin D. It is a disease in which the bones of the child fail to harden through lack of deposition of the salts of calcium and phosphorus. If the condition remains uncorrected for any length of time, distortion of the skeleton will result. Importance also is attached to the association of vitamin D with the hardening and preservation of teeth. Cod-liver oil contains vitamin D, and so does coconut oil, but to a lesser extent. Some other fish oils, such as halibut-liver oil, egg yolks, and milk contain this vitamin.

Exposure to sunlight, or the use of foods which have been irradiated with ultraviolet light in the laboratory, may prevent the development of rickets. Rickets tends to be a common disease of the children of the poor in crowded cities, where the direct rays of sunlight are not available, and in families where little effort is made to provide proper diet.

Vitamin B. Beriberi is a common deficiency disease in Oriental countries. It is a disease of the nervous system, which eventually results in partial paralysis or death. It develops when people live on an exclusive diet of polished rice. The vitamin, known as vitamin B, is present in the husks of the rice, but is not in the polished product. It appears that vitamin B is essential to normal growth and normal activity of the nervous system. Among other sources of this vitamin are the germ of wheat, spinach, potatoes, beets, onions, carrots, and eggs. In recent years investigators have divided vitamin B into several factors, designated as B_1, B_2, B_3, B_4, and B_5. The so-called B_2 (otherwise known as vitamin G) has been associated with the disease pellagra, but this association has been questioned.

Vitamin A. Vitamin A, which is present in cod-liver oil, egg yolk, butterfat, yellow corn, liver, leafy vegetables, and especially yellow-pigmented vegetables such as carrots, serves to prevent development of a disease which affects the epithelial tissues, and often centers about the eyes. Absence of vitamin A in the diet is also associated with failure to grow normally in youth. Evi-

TABLE III. THE VITAMINS

	SOURCES	CONDITION ASSOCIATED WITH DEFICIENCY
Vitamin A	Cod-liver oil, butter, egg yolk, green leaves, carrots, sweet potatoes, yellow corn, whole wheat, string beans, cabbage, cantaloupe, liver, beef fat, milk.	Eye and skin diseases; failure to grow normally.
Vitamin B	Milk, eggs, butter, spinach, beets, onions, carrots, potatoes, nuts, fruits, asparagus, beans, celery, germ of wheat, yeast, husks of grain, beef fat.	Beriberi.
Vitamin C	Fresh fruits and vegetables, especially lemons, oranges, tomatoes, apples, bananas, string beans, cabbage and carrots; some in fresh milk and meat.	Scurvy.
Vitamin D	Cod-liver oil, butterfat, egg yolks, coconut oil, irradiated foods.	Rickets.
Vitamin E	Milk, egg yolk, unpolished rice, germ of whole wheat, lettuce.	Retarded sexual development.

dence is being gathered to the effect that vitamin A may be essential to proper development and preservation of the teeth and to the ability to resist certain infections, such as infections of the ears, lungs, throat, and kidneys.

It has been known for some time that vegetables containing the yellow pigment carotene were good sources of vitamin A. It recently has been discovered that this carotene, synthesized by the plant, may be converted into vitamin A by the animal body, or at least it is not stored in the animal body in the form of carotene.

Vitamin E. Vitamin E, found in the germ of wheat, leafy vegetables, milk fat, and a number of other substances, appears to be necessary to normal development of the reproductory function in young animals.

Some other relationships between vitamins and diseases may be discovered in the future. As has been suggested, our present knowledge of vitamins is by no means complete. They are important because they are necessary to good nutrition, which is another way of saying that they are necessary to the successful use of energy in the animal body.

A CORRECT DIET PROMOTES HEALTH

When we say that a "correct" diet promotes health in the case of man, we mean of course a *relatively* correct diet. Individuals vary, and as a result, a diet suitable for one individual might not be wholly suitable for another. The whole problem of diet is subject to discoveries that may be made from day to day. The real issue sometimes has been obscured by extreme ideas and "fads" with regard to foods.

Indigestion. It should be remembered that indigestion sometimes occurs when the diet is not at fault, because the mental state may affect the digestive processes. To a certain extent digestion is controlled or affected by the nervous system. In certain cases the digestive processes may be slowed down under the influence of the nervous system. The result is that bacterial decomposition of food takes place. The bacteria secrete poisons which enter the blood and produce such effects as headache, drowsiness, fatigue, and others, which, taken together under these circumstances, constitute the condition known as "autointoxication." Since protein is particularly subject to bacterial decay, overeating of proteins may be a common cause of autointoxication.

Overeating. It is probable that a good many people overeat habitually. Strangely enough, overeating is not followed by a lack of appetite. On the contrary, once the habit is formed, it is likely to be continued. It also is possible to develop a habit of undereating. People who overeat are likely to be overweight, may be victims of autointoxication, and may develop hardening of the arteries in later life, although other factors may be responsible for all of these results. People who undereat are likely to be underweight, sensitive to cold, and lacking in energy.

Body weight. Undoubtedly there is a loss of efficiency involved in being overweight. For one thing, an unnatural strain is put upon the heart. The heart is able to respond up to a certain point, but this lowers its reserve strength — its margin of safety. It is significant that the death rate is high among people who are overweight after the age of forty. Cases of diabetes which occur in later life are relatively common among people who are overweight.

One thing that most of us are likely to forget, in relation to being overweight or underweight, is that normal weight is maintained when the income of food is balanced by the use of energy. In other words, when the food eaten is just sufficient to meet the needs of metabolism within the body. This, of course, varies with the individual, since the rate of metabolism may fluctuate.

Loss of weight, then, is largely a matter of exercising will power, if the metabolism of the individual is normal. Foods that are bulky, but do not contain a large amount of potential energy, are generally recommended. Proteins are included because moderate amounts are satisfying to hunger and they appear to stimulate the process of oxidation within the body. But if too much protein is eaten, some of this material may be changed into sugar or fat. Fats, in moderate amount, are preferred to carbohydrates, because if a meal is very low in fat content it may be followed by renewed hunger in a short time. Of course, in any diet, attention must be given to the matter of vitamin content. But a good variety of foods including cooked vegetables and a portion of raw food every day usually is sufficient to take care of the vitamin needs.

The Eskimos eat fats and proteins almost altogether. This is because they usually are unable to get carbohydrates. In such case the body probably converts excess proteins into such sugars as may be needed.

Fuel values of foods. We have spoken of foods which contain little potential energy. Other foods contain larger amounts of potential energy. We express this matter by saying that a food has a certain "fuel value." As we have seen, fuel values are measured in terms of calories. When we say that a given amount of food contains 100 calories, we mean that the oxidation of this amount of food will liberate 100 calories of heat energy. The human body does not utilize all of the potential energy in the food that is eaten.

Competent authorities now estimate the actual needs of the average person (adult) to be met by a fuel value of thirteen

TABLE IV. FUEL VALUES OF FOODS

FOOD	FUEL VALUE (in large calories) per pound	PER CENT CARBOHYDRATE	PER CENT FAT	PER CENT PROTEIN
Apples	214	10.8	.5	.4
Bacon	2840		64.8	10.5
Bananas	290	14.3	.4	.8
Beans (baked)	583	19.8	2.5	6.9
Beans (string)	176	6.9	.3	2.1
Beef (fat)	1721		35.6	21.9
Beef (lean)	617		5.4	21.9
Bread	1284	57.3	2.2	9.6
Butter	3491		85.	1.
Cabbage	143	5.6	.3	1.6
Cheese (cream)	1885	2.4	33.7	25.9
Chicken	289		1.4	12.8
Chocolate	2625	30.3	48.7	12.9
Eggs	594		9.3	11.9
Fish (perch)	275		.7	12.8
Grapefruit	170	8.6	.4	.5
Ham (lean)	1209		20.8	19.8
Lettuce	83	3.	.3	.1
Milk (whole)	314	5.	4.	3.3
Mutton	1543		30.9	15.6
Oranges	170	8.6	.4	.5
Oysters	228	3.7	1.2	6.2
Peas	252	9.8	.2	3.6
Pork (loin)	1245		24.2	13.4
Potatoes	302	20.6	.1	1.8
Rice	1591	77.9	.3	8.
Tomatoes	100	3.9	.4	.9
Veal	683		7.7	20.3

and a half calories for every pound of body weight. Other estimates place the average daily requirement at 2500 to 3000 calories per person per day. All of these figures are subject to variation. For instance, if the individual does hard manual work, or indulges in a good deal of exercise — playing football, perhaps — the figure would be higher. And it would be lower for the person whose daily routine includes little exercise.

Growing children require more food than that represented by their expenditure of energy alone. Probably twenty calories per pound of body weight, per day, would be very near the requirements of a moderately active boy or girl of high-school age.

What constitutes a proper diet? A diet which will furnish both growth materials and energy, and will also maintain a proper tone and balance of body functions, requires other factors than those stated in terms of calories. It is not possible or desirable to establish a standard diet for all persons. Physical condition, weight, age, and activity make necessary different standards. Certain principles, however, may be stated as results of experiments on food requirements.

Some Principles for Guidance in Selecting a Diet[1]

1. Eat a variety of foods: avoid excess of one kind.
2. Consider twenty calories per pound of body weight the basic amount of fuel value needed per day. Increase or decrease this value according to individual needs.
3. Consider that one seventh of the total fuel value should be protein. This may be more for children, convalescents, or for those doing hard, manual labor.
4. Eat some raw vegetable food and some fruit daily.
5. Drink from six to eight glasses of water daily.
6. Drink one glass of milk — more if you like it — daily.
7. Avoid eating too much at one time and allow from three to five hours between meals.
8. Do not eat directly before, or immediately after, severe exercise.
9. Allow one hour after a meal before going to bed or before bathing.

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[1] For the young, active, normal person.

Water. As we have learned in our earlier studies, water is essential to living substance, and has many uses in the animal body. It is necessary to normal metabolism, to growth, and to the repair or formation of tissues. For these reasons, it is an important part of the diet.

Minerals. We also have learned that protoplasm contains mineral matter, and so the inclusion of mineral matter in the diet becomes a matter of importance. The mineral matter required includes salts of calcium and potassium. Such mineral matter is urgently needed during the period of development and growth, but some also is required in later life. As we might expect, milk contains these mineral compounds in about the required proportions for the growing animal. It is estimated that the average person eats about ten pounds of salt (sodium chloride) per year. We have seen that hydrochloric acid is a constant requirement of the gastric juice and this acid is made from the salt eaten by animals. Herbivorous animals, such as cattle or deer, appear to require relatively larger amounts of this mineral compound.

It is certain that iodine from some source must be supplied to the body. An attempt is made to supply deficiency in this element by including it in common salt. We have learned that iron is necessary to the human body because it is necessary to the formation of hæmoglobin (in blood), which is essential to the process of respiration.

CERTAIN IMPORTANT DISEASES ARE ASSOCIATED WITH THE HUMAN DIGESTIVE SYSTEM

Food poisoning. The matter of food poisoning is one that frequently receives attention. Food may become poisonous because of the activity of bacteria of certain kinds, which causes decay of the food. Fortunately, many foods may undergo a certain amount of decay without becoming dangerous. In other cases, the decomposed foods are dangerous, probably even if the bacteria in them have been killed. The most common acute cases of food poisoning have followed the eating of presumably "spoiled" meat, including such sea foods as fish or oysters. In cases of this type a physician should be consulted. If the victim is not too badly shocked and prostrated by poisoning of this type, recovery is relatively rapid. Death occurs in some cases.

Foods which show signs of decay should not be eaten. In one type of food spoilage, the ends of tin cans in which the food has been preserved become bulged outward. In the interest of safety, the contents of such cans should not be eaten, because they may prove to be extremely poisonous. The bulging of the cans may be due to bacterial activity within them. This suggests that the contents of the cans were not sterilized after the cans were sealed. As a general practice it is well to avoid eating foods which have an abnormal taste or smell; the presence of such taste or smell suggests that the foods may have undergone decay.

In general, food poisoning may result from the following causes:

1. The presence of certain bacteria in the food.
2. The presence of toxins resulting from the activity of certain bacteria, or the presence of poisonous material resulting from decay.
3. The presence of some poisonous substance, as in the case of certain species of poisonous mushrooms.

There are some interesting cases of people who may develop hives and suffer digestive disturbances after eating foods which do not cause such unpleasant results when they are eaten by the majority of people. Foods sometimes involved include eggs, oysters, shrimp, fruits, onions, oatmeal, and even milk. Obviously these foods are harmless to most people, but occasional persons may be sensitive to one or more of them, or to other foods not named in this list.

Drugs and poisons. Morphine, opium, and cocaine are habit-forming drugs. The person who uses these drugs sooner or later becomes a slave to the practice. These drugs may give the user temporary satisfaction, but his health is soon undermined and finally destroyed. The nervous system becomes injured, and insanity often results. Drugs such as morphine, opium, and cocaine should never be taken except as they may be prescribed by a physician.

Alcohol may also prove to be a habit-forming drug in many cases. The chronic user becomes what is known as an "alcoholic." Poverty, inefficiency, and vice are associated with chronic alcoholism. Alcohol may sometimes be prescribed as a medicine, but this is not a common practice.

To a lesser extent the drugs in tobacco, tea, and coffee may prove to be injurious. The tobacco habit may be injurious to young people. Many athletic coaches ask their athletes to abstain from the use of tobacco during the playing season. Tea and coffee are stimulants. They may not be harmful to healthy adults, unless used in excessive amounts. On the other hand, people suffering from certain diseases should not indulge in stimulants.

Not all of the foregoing substances and drugs enter the body by way of the stomach. Their effects often are upon other organs or systems of the body. They have been grouped together in this discussion for the sake of convenience.

Worm parasites. Trichina worms, which are dangerous parasites, and other worm parasites, sometimes are present in meats. Much more will be learned about these parasites in a later discussion.

Constipation and diarrhea. Among the more common digestive troubles are constipation and diarrhea. Both of these conditions *may* be due to improper diet. If bulk or roughage is absent in the food, constipation may result. On the other hand, eating of foods having bulk but not much food value may result in the development of diarrhea. Constipation may be due to a lack of water; the normal consumption is about six glasses per day. Diarrhea may be due to irritation of the intestine, produced mechanically, or may be due to drugs or bacteria in the food.

Appendicitis. Appendicitis is associated with the digestive system. An infection develops in the appendix, probably after the wall of the appendix has been injured by hard particles of fecal matter, rendered hard through constipation, although there are other possible causes. Appendicitis was not recognized as such until comparatively recent times, and no doubt many people died as a result of the disease. Modern medical science provides effective treatment in the great majority of cases.

Typhoid fever. Typhoid fever is a disease in which certain bacteria produce sores on the lining of the intestine. These bacteria also enter the blood and pass to other parts of the body. They gain entrance to the body through the medium of foods (usually liquids). We shall learn more about typhoid fever in a later discussion.

Summary. In conclusion we may observe that the growing organism requires proteins, carbohydrates, fats, mineral salts, vitamins, and water. These substances are used variously in the building of tissues and the release of energy. They also are required by the adult organism, but in different amounts and proportions. We see that good nutrition depends upon a number of factors, such as the age, physical condition, and amount of work done by the organism.

Faulty diet may lead to the development of various disorders of the digestive system and other systems in the body. Other diseases associated with the digestive system result from the activities of bacteria.

The eating, digesting, and absorbing of food represents a first step in preparing to utilize energy within the animal body. The greater part of this work is carried on by the digestive and circulatory systems.

SUGGESTED ACTIVITIES

Scientific methods

A scientist identifies substances by their peculiar qualities or chemical behavior.

1. Using charts or models, study and report upon the structure and functions of the digestive canal (man), including glands whose secretions are related to the process of digestion.
2. Trace the digestion of a meal consisting of bread, butter, meat, potatoes, and salad. State the nutrients digested in the mouth, the stomach, and the intestine; name the enzymes involved in each case, and indicate the products of digestion.
3. In each of two test tubes put one-quarter teaspoonful of starch paste. To one add 10 cc. of saliva, and to the other (the control) add 10 cc.

of water. Set both tubes in a water bath at a temperature of 90°–99° F. for twenty-four hours. Test a sample from each tube by warming gently to the boiling point after adding Fehling's solution. The formation of a reddish, green, or yellowish precipitate indicates the presence of sugar. Test another sample from each tube with a weak iodine solution. If starch is present, a dark-blue color will appear. What is indicated by the results of this experiment?

4. Prepare an artificial gastric juice (100 cc. of 0.4 per cent hydrochloric acid and 2 gms. of pepsin) and test its solvent action upon several substances, such as raw beef, roast meat, fried meat, gelatin, starch, the cooked white of an egg, and a piece of tendon. Use pieces of material approximately the same in size, and cover in test tubes with a volume of gastric juice twenty times that of the food. Set all of the samples in a water bath, and keep them between 90° and 99° F. for twenty hours. Examine the samples, and record the results in a table.

5. With the aid of a microscope, examine the cross section of a frog's stomach. Locate the mucous coat — the inner lining of epithelial cells. Observe the gastric glands. Note the circular and longitudinal muscles of the stomach wall.

6. Dissect out (demonstration) the digestive canal and related glands of a frog. Use the description on pages 155 and 156 in identifying the various structures.

7. Testing exercise:

   Number from 1 to 20 on a piece of paper and after each number write the word that should replace the correspondingly numbered blank in the following paragraph in order to complete the meaning.

   Digestion is a process of making food ready for (1) .... In the human body digestion of food begins in the (2) .... and is continued in the (3) .... and the (4) .... The enzyme in the saliva is (5) .... which acts only in a neutral or (6) .... medium. The gastric juice contains the enzymes (7) ...., (8) .... and a (9) .... splitting enzyme. Gastric juice also contains (10) .... acid. Pepsin acts upon (11) .... but these are more completely digested in the (12) .... where (13) .... from the (14) .... juice and .... from the (15) .... fluid act upon them. Structures which secrete enzymes are known as (16) .... Absorption is rendered more efficient by the presence of fingerlike structures known as (17) .... which line the (18) .... intestine. Fats are acted upon by enzymes known as (19) .... Carbohydrates are finally converted into (20) ....

SUMMARY OF PRINCIPLES

1. Animals differ in food habits and are classified as herbivorous, carnivorous, and omnivorous.
2. Digestion consists of breaking down complex compounds into simpler compounds capable of being absorbed.
3. Digestion in man occurs in the mouth, the stomach, and the small intestine.
4. Absorption of digested food in man occurs chiefly in the walls of the small intestine.
5. The digested foods pass through the walls of the villi into the blood capillaries and lacteals.
6. Vitamins are essential to good nutrition; their absence results in the so-called deficiency diseases.
7. The diet of any individual should vary with special needs. Human requirements, on the average, are estimated as thirteen and a half calories for each pound of body weight (adult).
8. Water and certain mineral compounds are essential factors in the diet.
9. Various diseases of the digestive tract result from improper diet and from the presence of bacteria.

GUIDE QUESTIONS

1. Name five herbivorous animals.
2. Name five carnivorous animals.
3. Why is the house rat said to be omnivorous?
4. How may "digestion" be defined?
5. Name the successive parts of the digestive canal of a vertebrate.
6. Name three glands connected to the digestive canal by ducts.
7. Why does the herbivorous animal have a relatively long digestive canal?
8. Name the kinds of teeth on one side of each jaw and give the number of each kind in the permanent teeth of man.
9. What fluid and what enzyme are secreted by glands of the human mouth region?
10. Name the fluid secreted in the stomach (man) and state the function of each enzyme contained in this fluid.
11. Name the enzymes in the pancreatic juice (man), which act respectively upon fats, proteins, and carbohydrates.
12. Where and how are digested foods absorbed into the human blood?
13. What are the end products of the digestion of fats, proteins, and carbohydrates in man?

14. What is the meaning of "deficiency disease"?
15. Name three deficiency diseases, a vitamin associated with each, and two foods which supply the necessary vitamin for prevention of the disease.
16. How would you define "correct diet"?
17. Why do individuals differ as to the number of calories required per day?
18. Why are certain mineral compounds essential to good nutrition?
19. Describe two types of food poisoning.
20. What is the association between being overweight and the development of heart diseases?

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CHAPTER XV

CIRCULATION IN ANIMALS

Problems:

1. What are the functions of circulation in the animal body?
2. In what ways are the circulatory systems of animals similar and dissimilar?
3. How is circulation of the blood regulated?
4. What common diseases of man are associated with the circulatory system?

CIRCULATION HAS A NUMBER OF FUNCTIONS

Circulation. In the preceding chapter we learned that one function of the human circulatory system is to transport absorbed food materials. This is one step in the chain of related processes that have to do with the use of energy in the animal body. We shall now extend our studies to some other functions of the circulatory system that also have to do with the use of energy.

In the human body, circulation of the blood is concerned in the following processes, and in some of these processes in the bodies of less complex animals:

1. Distribution of food to the cells of the body.
2. Distribution of heat within the body.
3. Regulation of water content and distribution within the body.
4. Removal of liquid wastes.
5. Removal of gaseous wastes.
6. Distribution of oxygen to the cells of the body.
7. Acts as a carrying medium for hormones.

Transportation of food. In our studies of some of the simpler and smaller forms of life, we found that it was not unusual for all of the cells in the body of an organism to carry on their own digestive processes. In such cases no distribution of food from

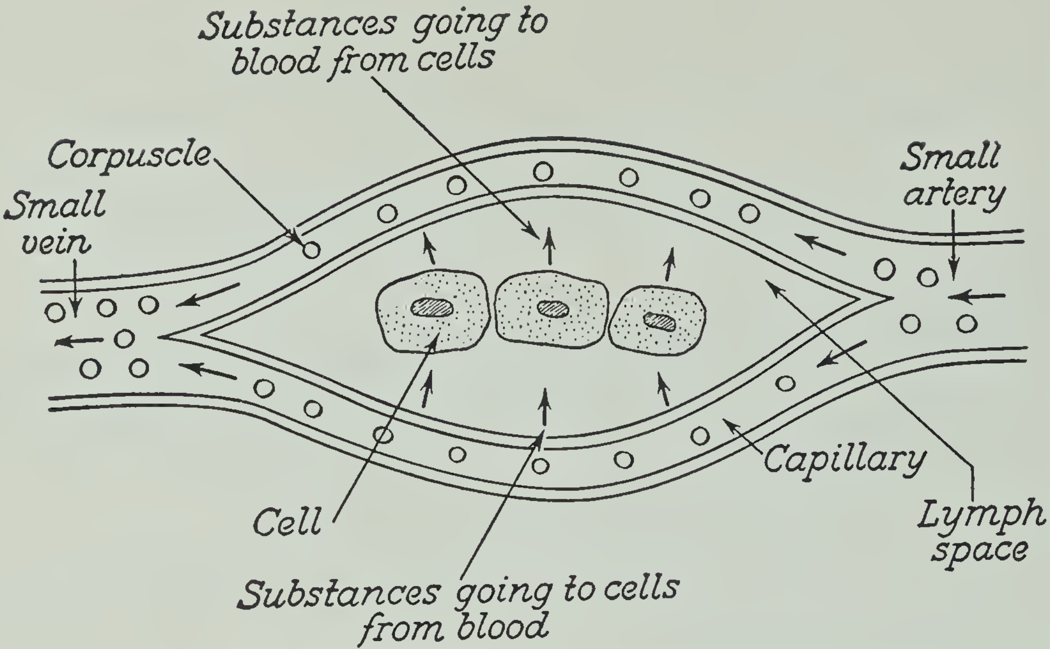
Substances going to blood from cells
Corpuscle
Small vein
Small artery
Capillary
Lymph space
Cell
Substances going to cells from blood

FIGURE 126. Diagram showing the relationship of capillaries to the cells of tissues.

a specialized digestive center was necessary. But when we study the structure of a larger and more complex organism, we find that many cells are removed from the exterior and from the digestive center. In such case there must be some way in which food materials are supplied to the isolated cells. This work is done by the circulatory system. The cells of the body are bathed in lymph, a fluid which comes from blood plasma (see page 269). From this lymph the cells receive their supplies of food.

Removal of wastes. Wastes are constantly being formed in active cells. In man, these wastes are collected by the blood. Carbon dioxide waste is removed from the body as blood passes through the lungs. Protein wastes are removed from the blood by the kidneys.

Distribution of heat and water. Oxidation within cells results in the release of energy, much of which is in the form of heat. Another function of the human circulation is to equalize heat within the body. Provision is made for the discharge of excess heat through the agency of breathing, and through the skin. In addition, the blood is involved in maintaining a normal content and a normal distribution of water.

Circulation and respiration. The distribution of oxygen to the cells of the body is another function performed in part by the blood and the circulation of higher animals such as man. Oxygen is taken into the blood at the time that the blood is discharging its carbon-dioxide waste.

The oxygenated ("pure") blood of man is blood containing little carbon dioxide and a relatively large amount of oxygen. On the other hand, the venous ("impure") blood is blood containing little oxygen and a relatively large amount of carbon dioxide. In order that blood may carry oxygen it is necessary that it contain the compound hæmoglobin. Hæmoglobin is a red-colored protein which contains iron; it has a strong affinity for oxygen. Hæmoglobin that has combined with oxygen has the bright red color that is characteristic of oxygenated blood. Venous blood is dark red in color.

It should now be obvious that circulation is intimately related to the use of energy in the animal body. It is the means whereby the cells are supplied with food materials, and with oxygen. After oxidation has taken place, carbon dioxide and liquid wastes are removed from the cells through the agency of the blood. Excess heat, which results from oxidation, tends to be distributed by the circulatory system.

THE STRUCTURE OF BLOOD IS NOT THE SAME IN ALL SPECIES

Plasma. The basic fluid of the blood is called plasma. In this plasma small cellular structures called corpuscles are suspended. We ordinarily think of the plasma as being a colorless or nearly colorless fluid. But this is not true in all cases. The plasma of an earthworm, for instance, is red in color. For in an earthworm, the plasma contains the red-colored hæmoglobin. The corpuscles of an earthworm's blood are colorless, or nearly so.

In the case of insects, the plasma is a colorless or yellowish fluid. It contains no red corpuscles. Evidently the function of circulation in insects is limited largely to distribution of food, since other adaptations provide for respiration and the removal of liquid wastes.

Frog blood. We may recall from previous studies that a frog's blood consists of a plasma containing red corpuscles, white corpuscles, and spindle cells. The red corpuscles are oval and contain nuclei; the white corpuscles have ameboid powers.

Human blood. The blood of man differs from the blood of a frog in some particulars. Human-blood plasma is almost colorless, about 80 per cent water, and acts as a carrying medium for liquid and gaseous wastes, for foods, for hormones, and for the corpuscles. White corpuscles are present; they really are gray in color, and contain from one to three nuclei. Like the white corpuscles of frog's blood they have ameboid powers and serve to destroy invading bacteria. The red corpuscles differ from those of a frog in being disc-shaped and in the fact that they do not have nuclei when mature. These red corpuscles contain hæmoglobin and are the oxygen carriers of the blood.

CIRCULATION OF THE BLOOD DEPENDS UPON CONTRACTION OF THE HEART (MAN)

Harvey. Demonstration of the fact that blood circulates was not made public until the year 1628, when William Harvey (1578–1657), of London, published the results of his experiments. Andreas Vesalius of Belgium had published his work on the structure of the human body in 1543. Until this date knowledge of the human body depended largely upon the studies of the Greek and Roman physician Galen. Galen's work was good for its day, but the fact that no real improvement upon it occurred for fifteen centuries testifies to the lack of progressive learning during the Middle Ages.

Hearts. When we examine the circulatory systems of animals, we generally find that the contraction of some blood vessel or of a heart serves to produce a circulation of the blood. A circulation of the blood is of course essential if the functions described in the preceding pages are to be performed.

We have observed the five pairs of "hearts" of an earthworm. These structures are blood vessels which are able to pulsate or contract and thus produce a movement of the blood. But these "hearts" are very simple in structure when compared with the hearts of more complex animals.

Hearts of sharks and fishes. The sharks and the fishes have hearts composed of two main chambers. The heart of a shark, for instance, has an auricle and a ventricle. The auricle receives incoming blood, and the ventricle pumps it out of the heart. Since the ventricle is the pumping structure, we are not surprised to find that its walls are more muscular than the walls of the auricle.

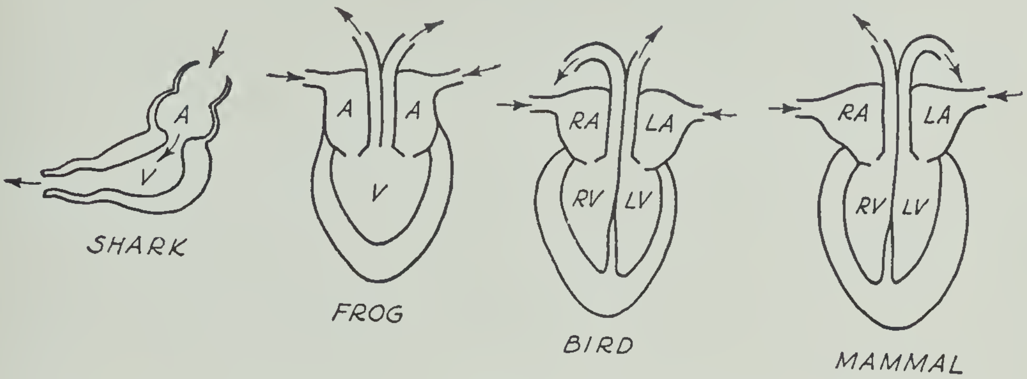

FIGURE 127. Diagram illustrating the number of heart chambers in four types of vertebrates (*A*, auricle; *V*, ventricle).

Frog heart. In the case of a frog, the heart has three chambers. This is due to the fact that a muscular partition is developed in the auricle, separating it into two parts, a right auricle and a left auricle. There is a partial division of the ventricle, but it is not sufficiently developed to prevent blood from passing from one side of the ventricle to the other side.

Hearts of reptiles. The heart of a reptile, such as the turtle, is similar to that of a frog. That is, a turtle has a three-chambered heart, and there is a partial division of the ventricle. This division of the ventricle has proceeded further in the turtle than in the case of a frog. In fact, some of the reptiles, such as crocodiles and alligators, have completely divided ventricles. When this occurs, the heart becomes four-chambered.

Hearts of birds and mammals. Birds and mammals have four-chambered hearts. In such cases the heart consists of a right ventricle, a left ventricle, a right auricle, and a left auricle.

Birds and mammals are warm-blooded. On the other hand, animals not possessing four-chambered hearts are cold-blooded. In the case of the warm-blooded animal the body temperature tends to remain more or less constant, or to vary within definite limits. Exceptions occur in cases of disease, and in the case of mammals which undergo the "winter sleep" known as hibernation. In the case of cold-blooded animals the body temperature varies with the rise and fall of the surrounding temperature.

VEINS CARRY BLOOD TO THE HEART; ARTERIES CARRY BLOOD AWAY FROM THE HEART

It sometimes is stated that a vein carries "impure" blood and an artery carries "pure" blood. This, however, is a very poor and misleading definition, even if we interpret "pure" to mean oxygenated and "impure" to mean venous. An examination of the circulation of a shark, for example, will reveal that some of the arteries carry venous blood. The pulmonary arteries of man carry venous blood, while the pulmonary veins carry oxygenated blood.

Veins and arteries. A better distinction between arteries and veins (man) lies in the fact that arteries carry blood away from the heart while veins carry blood toward the heart.[1] We use the term blood vessel as including both arteries and veins.

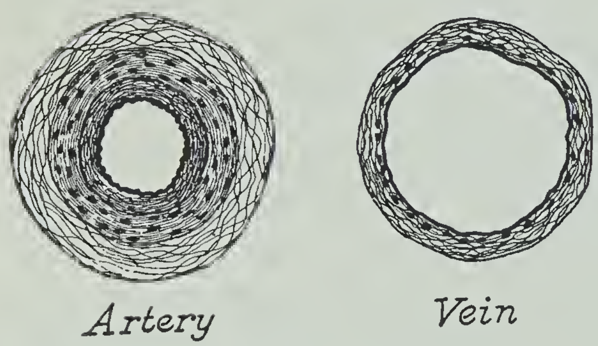

FIGURE 128. Cross section of a vein and an artery (diagram). Which of these blood vessels is adapted to withstand the greater pressure?

The wall of an artery generally is more muscular than the wall of a vein. This is necessary, because the blood in an artery, having come directly from the heart, is under considerable pressure. The muscular wall of the artery is elastic and allows the artery to expand and contract as the pressure increases and diminishes. An artery receiving blood directly from the heart must withstand the greatest pressure. A branch of this artery, farther removed from the heart, would be subjected to less pressure. Pressure generally is lower in the veins than in the arteries.

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[1] In man the coronary arteries carry blood to the wall of the heart.

Capillaries. Capillaries are the tiny vessels which connect the end branches of veins and arteries. Capillaries uniting a vein and an artery in the same region form what is known as a capillary network. This permits the blood from the artery to pass over to the vein. It is the sort of arrangement we find in human lung tissue, or in the capillary network of the intestine. In the capillary region the blood comes into most intimate contact with the cells of the body. It is in this region that part of the plasma escapes from the capillaries in the form of lymph.

Strange to say, blood pressure is lowest in the region of the capillaries. It begins to increase again as the blood is collected by the veins and proceeds back toward the heart. The explanation lies in the fact that capillaries, although small, are very numerous. Their combined capacity is greater than that of either the arteries or the veins.

CIRCULATION IS IN PART REGULATED BY THE NERVOUS SYSTEM

In considering regulation of circulation we shall limit our discussion to the more complex animals such as man and the higher vertebrates.

Cardiac muscle. The wall of the heart is composed of a special type of muscle known as cardiac muscle. The cells of cardiac muscle have automatic properties. The heart of a frog, for instance, will continue to contract for a time after it has been removed from the body. However, branches of the vagus nerves connect with the muscles of the heart and serve to regulate contraction. The vagus nerves are a pair of nerves that arise directly from the brain. They are present in the leopard frog, the domesticated cat, man, and other higher animals. The effect of the vagus nerves upon the heart seems to be a slowing down and regulating of the rate of contraction.

Contraction and relaxation. In man, contraction of the heart and relaxation of the heart occupy about equal intervals of time. If the heart is contracting seventy-five times per minute, contraction will occupy .4 of a second, and the cardiac muscles will be relaxed for .4 of a second during each cycle. Thus it follows that the heart is not active continually, but rests about half of the time.

The pulse. We now may understand why blood pressure rises and falls at a given point in an artery. The rise in pressure follows a contraction of the heart which forces blood into an artery. The fall in pressure follows a period of heart relaxation. The "pulse" represents the momentary swelling of an artery, following a contraction of the heart.

In the following chapter we shall learn how at least one hormone may serve to regulate the circulation to some extent in the case of man and some other higher vertebrates. It will be found that this hormone (epinephrine) causes blood vessels to contract. If blood vessels are contracted in one particular region, relatively more blood will flow to and from the regions not so affected.

Regulation of blood flow within the human heart depends upon a system of valves. These valves permit the blood to flow only in one direction.

We have learned that circulation of blood is intimately concerned with the use of energy in the animal body. Now we find that human circulation is regulated by action of the nervous system and through the secretion of certain hormones. In the metabolism of a complex organism we find that many processes are related to one another.

THE PULMONARY CIRCULATION (MAN)

In man, the pulmonary circulation is the circulation from the heart to the lungs, and back again to the heart. Venous blood from all parts of the body is returned by the veins to the right auricle. This blood now passes into the right ventricle, which contracts, driving the blood through the pulmonary arteries to the lungs. After the blood has been oxygenated, it returns by way of the pulmonary veins to the left auricle. The blood then passes into the left ventricle, which contracts, forcing the blood out through the arteries to the various parts of the body.

In a frog. We may recall that the situation in the case of the leopard frog is similar, but presents some interesting differences. Instead of having two pulmonary arteries, this frog has two similar arteries, each of which divides into two branches. One pair of these branches go to the lungs, the other pair to the skin. Instead of having two pulmonary veins from the lungs to the heart, the frog has two corresponding veins. Each of these veins receives a branch from a lung and a branch from the skin. The explanation is that the frog uses both lungs and skin in respiration.

In all cases the pulmonary circulation involves the oxygenation of blood. Venous blood passes to a respiratory center (lung, gill, or skin), where it discharges carbon-dioxide waste and obtains oxygen. After this has occurred, the blood is said to have been oxygenated.

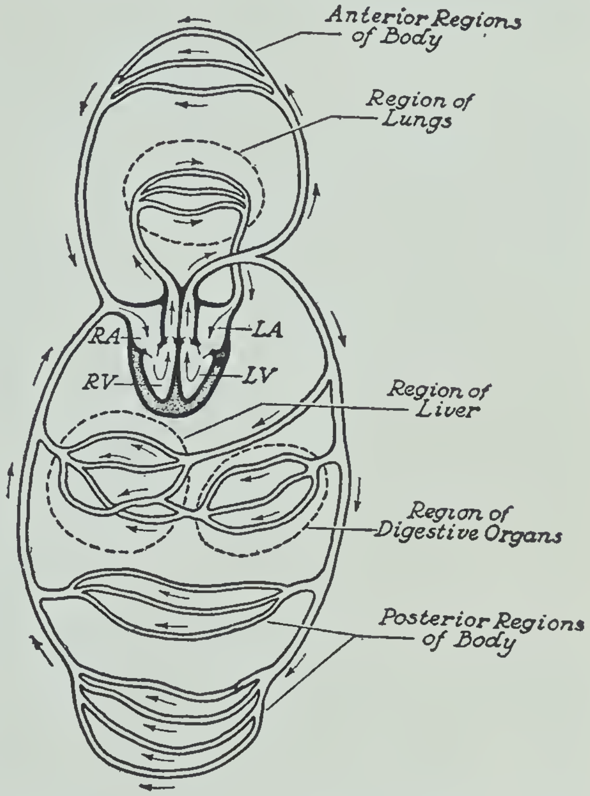

FIGURE 129. Diagram illustrating the course of circulation in the human body. The pulmonary circulation includes circulation from the heart to the lungs, and back again to the heart. The rest of the circulation is referred to as the general circulation.

THE GENERAL CIRCULATION (MAN)

The general circulation. We have learned that in man the pulmonary circulation includes circulation from the heart to the lungs and back again to the heart. The general circulation includes the circulation from the heart to the various parts of the body (except the lungs) and back again to the heart. As previously stated, arteries convey the blood away from the heart, and veins return the blood to the heart.

Arteries. It will not be our purpose to study the many branches of the general system of man, but only some of the more important vessels. The so-called aortic arch receives the blood pumped out of the heart by the left ventricle. This aortic arch curves to the left side of the body after leaving the heart. It gives off a number of arteries to the regions of the head, arms, and shoulders, and then continues posteriorly as the dorsal aorta. The dorsal aorta, in turn, gives off arteries to the organs of the abdominal region, the muscles of the body wall, and to the legs. These vessels carry blood containing oxygen and food materials to the different regions of the body.

Veins. The veins of the head, arms, and shoulders discharge their blood into the superior vena cava, which conveys blood posteriorly to the right auricle of the heart. The veins from the posterior part of the body discharge into the inferior vena cava, which conveys the blood anteriorly and discharges into the right auricle of the heart.

The portal system. In another place special reference has been made to the portal system of man, because of its importance in connection with the process of digestion. In reality, the portal system is part of the general system of veins. It consists of a number of veins which collect blood from the spleen, pancreas, and intestine. These vessels unite to form the portal tube, which passes into the liver. The liver regulates the sugar content of the blood, and stores excess sugar as glycogen.

When we recall the general circulation of the leopard frog we see that it is similar to that of man, but differs in certain details. In the frog, for instance, there are two aortic arches, a left aortic arch, and a right aortic arch. They unite behind and below the heart to form the dorsal aorta. There are other differences in the structure and arrangement of certain veins and arteries. These, however, have little significance in our present study.

Functions of the general circulation. The general circulation involves the distribution of oxygenated blood to the various parts of the body. This blood also contains food materials which have entered the blood by way of the portal blood vessels. Blood returning from the tissues carries waste products which have resulted from the activities of cells.

LYMPH

Functions of lymph. We have learned that plasma is the basic fluid of blood. Some of the plasma escapes through the thin walls of capillaries, and is then known as lymph. Lymph comes in direct contact with the cells of the body. From it each cell absorbs oxygen, water, and food materials. Wastes of the cells are meanwhile discharged into the lymph. Thus we see that lymph serves as a "go-between" for the cells and the capillaries.

We find in lymph such substances as foods, salts, oxygen, wastes, and some other materials. In most parts of the body the lymph is straw-colored. It contains few, if any, mature red corpuscles. Near the digestive region lymph is whitish because of the presence in it of fatty food substances.

Lymph vessels. Much of the lymph is to be found in spaces between the cells of the body. There are, however, a number of lymph vessels known as the lymphatics. These vessels resemble veins in structure. The lacteals, for example, are small lymph vessels in the intestinal region. They contain lymph that is carrying absorbed fat. The lacteals unite to form the thoracic duct. The latter extends forward in the body cavity and discharges into a large vein in the left shoulder region. The smaller right lymphatic duct receives branches from the right arm, and the right side of the head and neck. It discharges into a vein in the region of the right shoulder.

Lymph vessels contain valves which tend to keep the lymph moving in one direction. In certain places lymph vessels also contain groups of cells which are called lymph nodes. It is thought that lymph nodes tend to prevent the spread of infection in the body. Certain white cells of lymph are developed in the lymph nodes.

CERTAIN IMPORTANT DISEASES ARE ASSOCIATED WITH THE CIRCULATORY SYSTEM

Tonsils and adenoids. Tonsils are lymph glands. Sometimes they become infected by bacteria. Poisons from the bacteria enter the circulation and result in injury to health. Adenoids are composed of lymphoid tissue that has grown to a greater than normal extent; they are located in the upper back part of the throat cavity. In youth this tissue often increases in amount until it becomes a menace to health. Adenoids tend to prevent breathing through the nose. Mouth breathing and forced breathing in children tend to distort the shape of the jaws and the shape of the chest. Adenoids also may contribute to the development of deafness, and their presence always is irritating.

Anemia. Anemia is a condition in which the blood contains fewer than the normal number of red corpuscles, or the blood lacks a normal content of hæmoglobin. A lack of red corpuscles may be due to the fact that the red corpuscles have been destroyed by poisons in the blood. Such poisons may in turn be due to the presence of bacteria which are causing an infection in some part of the body. Anemia also may result from excessive bleeding, inability to produce new red corpuscles, or any factors which cause excessive destruction of red corpuscles.

High blood pressure. In persons over forty years of age it is quite common for the muscles forming the walls of the smaller arteries to contract. This contraction produces increased resistance to the flow of the blood and results in what is known as high blood pressure. Disease of the kidneys commonly accompanies this condition. The increased resistance to blood flow causes the heart to do extra work, and it gradually enlarges. This, in turn, may cause the heart to have little or no reserve strength.

Hardening of the arteries. Hardening of the arteries occurs when the muscular walls of these vessels become thickened and less elastic. Sometimes calcium salts are deposited in the walls of the arteries, making them brittle. While some hardening of the arteries always takes place as one grows older, this condition is much more pronounced in some people than in others. Severe infections, lead poisoning, mental strain, and severe muscular exertion seem to contribute to the development of this condition. It is also probably dependent upon the quality of muscle tissue inherited by the individual. The affected arteries eventually may rupture or break open, or they may become so thick-walled that the blood supply to certain parts of the body is greatly reduced.

Defective heart valves. The heart may be affected by injury to its valves. Sometimes the openings between the valves become too small, and sometimes the valves fail to close properly. Infections, such as tonsillitis, which sometimes spread into the blood stream, may result in infection and eroding of the heart valves. Eroding of the valves is often followed by permanent defects.

When the heart valves do not function properly, the heart has to work harder to overcome the handicap imposed upon it. As in the case of hardening of the arteries, the heart gradually becomes enlarged. Eventually it has no remaining reserve strength. In such cases the individual may suffer a "heart attack," or "heart failure."

Summary. In concluding our study of circulation, we find that human blood is involved in a number of functions. Among these functions are the distribution of foods and oxygen to the tissues, the distribution of heat, the carrying of hormones, and the removal of liquid and gaseous wastes from the tissues. In addition, we have noted that white corpuscles destroy some invading bacteria. All of the foregoing processes are related to the use of energy in the animal body. We find that in some of these activities the work of the circulatory system is associated with the work of other systems, especially the digestive, respiratory, excretory, and nervous systems. In a later discussion we shall learn that there also is an association between the work of the circulatory system and the activities of muscles.

SUGGESTED ACTIVITIES

Scientific methods

A scientist believes that the average of a large number of measurements, rather than one measurement, represents more nearly the truth.

1. With the aid of microscopes, examine prepared slides of human blood and frog blood. Attempt to locate white corpuscles in each case. Compare the two types of red corpuscles.

2. Examine the circulation of blood in the web of a frog's foot (demonstration with microscope).
3. Obtain a beef heart and compare its structure with a model or drawing of a mammalian heart.
4. Prepare a chart showing a comparison of heart structure in a fish, a frog, a reptile, a bird, and a mammal.
5. With the aid of a microscope or microprojector, examine cross sections of a vein and an artery. In what respects are they similar and in what respects do they differ?
6. Obtain the pulse rate of each member of the class. Calculate the average for boys and for girls. Design and perform an experiment to test the effect of mild exercise upon the pulse rate.
7. With the aid of charts, study the main paths of circulation in the human body. Prepare a chart which illustrates the course of circulation.
8. Arrange the following in the order in which the blood would pass through them, starting with the right auricle: right auricle, left auricle, right ventricle, left ventricle, aorta, veins, arteries, capillaries, pulmonary arteries, pulmonary veins, capillaries of the lungs.
9. Write the numbers 1 to 10 on a separate sheet of paper and indicate after each number the word true or false for the correspondingly numbered statements. If the statement is false make a correct statement involving the idea contained in the statement.
    1. All veins carry venous blood.
    2. All arteries carry blood away from the heart.
    3. White blood corpuscles are found only in the lymph vessels.
    4. Hæmoglobin is a compound containing iron.
    5. The circulation of the blood was demonstrated by Aristotle.
    6. The human liver stores sugar in the form of glycogen.
    7. The kidneys extract urea from the blood.
    8. The frog has a two-chambered heart.
    9. High blood pressure is related to hardening of the arteries.
    10. Absorbed foods are transported by the plasma of the blood.

SUMMARY OF PRINCIPLES

1. Circulation involves the process of distributing food and oxygen to the cells of the body, and of removing waste from them.
2. Circulatory systems show progressive development and specialization as we study successively higher forms of animal life.
3. The structure of the blood is not the same in all animals.

4. Circulation in animals is aided by muscular contraction of blood vessels, or by contraction of a heart.
5. Blood is carried by a system of tubes consisting of veins, arteries, and capillaries.
6. Veins carry blood to the heart and arteries carry blood away from the heart.
7. Circulation in the human body is regulated in part by the nervous system and in part by hormones.
8. In mammals oxygen is supplied to the blood and carbon dioxide removed from the blood in the capillaries of the lungs.
9. Hæmoglobin is a chemical compound of iron found in the red corpuscles (man) which combines with oxygen.
10. Most digested fats enter the blood stream by way of the lymphatic system.
11. Certain diseases of the heart and blood vessels may result from bacterial infections of various parts of the body.

GUIDE QUESTIONS

1. Name five functions of the blood.
2. How does the blood help to regulate body temperature?
3. What gases are exchanged by the blood and the cells?
4. Explain the method by which the blood carries oxygen.
5. What is meant by "oxygenated" and "venous" blood?
6. What are the chief constituents of the blood? Describe them.
7. What causes the blood to circulate in the case of man?
8. Who demonstrated the circulation of the blood?
9. Name an organism having: (*a*) five pairs of "hearts," (*b*) a two-chambered heart, (*c*) a three-chambered heart, (*d*) a four-chambered heart.
10. Define: (*a*) vein, (*b*) artery.
11. Distinguish between the systemic and pulmonary circulations
12. Describe the relationships of capillaries, veins, and arteries.
13. Distinguish between the terms lymph and plasma.
14. How is the sugar content of the blood regulated?
15. What are tonsils and adenoids, and what effects may they have upon health?
16. What are the probable causes of: (*a*) anemia, (*b*) high blood pressure, (*c*) hardening of the arteries?

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CHAPTER XVI

THE HORMONES

Problems:

1. What is the nature of hormones?
2. How do hormones affect metabolism in the human body?

HORMONES ARE REGULATORS OF METABOLISM

Hormones. Hormones are chemical substances secreted by certain ductless glands or glandular structures. These hormones are discharged into the blood and are carried to various parts of the body. We now wish to know how their presence affects metabolism, or the use of energy within the body.

At the present time, most of our information concerning hormones, or endocrines as they sometimes are called, pertains to man and the higher vertebrates. The study of hormones is one that has had its greatest development in recent times, and one that is being carried on most actively today. Great progress has been made, but undoubtedly much concerning this subject remains to be discovered.

Hormones and metabolism. Hormones influence metabolism. This is a very general statement, but different hormones produce different effects. They are regulators of metabolism in normal health, and apparently are very important in this capacity. However, as will be seen, diseased conditions may follow lack of secretion or too much secretion of certain hormones. In other words, the hormones may serve to unbalance metabolism if they are not secreted in normal amounts. Perhaps the best way to become familiar with the natures of these hormones is to study some specific cases. The following discussion will refer primarily to man.

INSULIN AFFECTS THE METABOLISM OF SUGAR

Insulin. In our previous studies we have discussed the pancreas as being a digestive gland. And so it is; but included in the pancreas are some groups of cells which secrete a hormone that is discharged into the blood. These groups of cells were described by Langerhans in 1869, and are now known as the "islands of Langerhans." They secrete the hormone known as insulin.

As early as 1788 the pancreas was associated with the disease diabetes. By 1899 this association had been confirmed by experimentation, and insulin was named in 1916. In 1921, a group of doctors, including F. G. Banting, C. H. Best, J. B. Collip, and J. J. Macleod, succeeded in extracting a fairly pure and active form of insulin from the pancreas. Later, a purer form was extracted by Dr. J. J. Abel and his associates.

Diabetes. Apparently in the presence of insulin in the blood, the sugar of the blood may be oxidized by the various cells of the body. In the absence or serious shortage of insulin, little or no sugar can be taken up by the tissues and oxidized. Consequently sugar begins to accumulate in the blood and to be removed by the kidneys. In other words, sugar appears in the urine.

After this condition of affairs continues for a time the kidneys remove the sugar almost as fast as it enters the body. At the same time, fat metabolism becomes faulty. Ordinarily, fats are oxidized so as to leave the harmless compounds carbon dioxide and water as end products. But when sugar metabolism becomes faulty, the end products of fat metabolism include acid compounds. These acid compounds in the blood produce the condition known as acidosis. The whole chain of events is recognized as representing the disease diabetes.

In treating cases of diabetes, commercial insulin is injected hypodermically to substitute for the insulin that ordinarily would be secreted by the islands of Langerhans. The presence of this introduced insulin restores the power of the blood to oxidize sugar, and this in turn corrects the faulty fat metabolism. The condition of acidosis then is relieved.

A HORMONE OF THE THYROID GLAND INFLUENCES THE RATE OF METABOLISM

Thyroid gland. The thyroid gland is located in the neck region. It consists of two connected lobes and consequently is spoken of as being a bilobed gland. Its size varies somewhat with age and sex; it tends to be larger in the female, in youth, and when nutrition is good.

Thyroxin. The thyroid gland develops a hormone that stimulates the rate of metabolism. In other words, it stimulates the rate of oxidation within the body. This hormone is called thyroxin, and it was not until the present century that it was isolated by Dr. E. C. Kendall of the Mayo Foundation. The human body may be adversely affected by the secretion of too much or too small an amount of thyroxin.

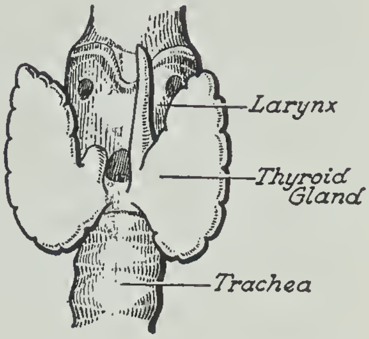

FIGURE 130. Diagram of the thyroid gland (man). Does this gland discharge its secretion through a duct?

Goiter. The condition known as simple goiter is associated with the secretion of an abnormally small amount of thyroxin. Thyroxin contains as much as 65 per cent of iodine, and simple goiter is most prevalent in regions where food and water are likely to be low in iodine content. Apparently the lack of iodine indirectly results in an enlargement of the thyroid gland, producing the so-called goiter.

Cretinism. A more serious state of affairs occurs when the thyroid gland apparently is less than normally active during early development, before birth. In such cases the head and abdomen become unusually large, the bones become thickened and irregular in form, the muscles are weak, and the mental condition is greatly affected. This condition is called cretinism.

Myxedema. Sometimes the thyroid gland begins to fail in the production of thyroxin during adult life. When this happens, the skin becomes rough and dry, the hair becomes coarse and tends to fall out, the face and hands become swollen in appearance, and there is general slowness of the mind and the body. This condition is known as myxedema.

Thyroxin used in medical practice. Naturally we are interested in knowing what can be done to relieve such conditions resulting from the secretion of less than a normal supply of thyroxin. In the first place, no great improvement of the cretin is possible, because the effects are too deep-seated and too well-developed before birth. But by the end of the nineteenth century it was recognized that the dried thyroids of pigs or sheep were beneficial to people who were deficient in the secretion of thyroxin. Then Dr. Kendall isolated thyroxin and it was found that the isolated product was effective in treating such cases. Recently an English scientist has succeeded in making thyroxin from coal-tar products, but this has not been done as yet upon a commercial scale.

Too much thyroxin. When the thyroid gland becomes unusually active and too much thyroxin is secreted, the rate of oxidation within the body is increased. A number of effects accompany this condition. The temperature of the body rises, the heart action becomes irregular, the eyeballs tend to protrude, and the victim is likely to be unable to sleep normally, and to be "nervous." Often the appetite is excellent, but nevertheless there is loss of weight. This is because the rate of metabolism increases, and the processes of digestion are disturbed. This condition is known as exophthalmic goiter. It is treated surgically, either by a removal of part of the thyroid gland, or by reducing the blood supply to the thyroid gland. In either case, the activity of the gland will be reduced, and this in turn will reduce its production of thyroxin.

A HORMONE OF THE ADRENAL GLANDS AFFECTS METABOLISM

In man, the adrenal glands are two structures, one lying adjacent to each of the kidneys. These glands first were described by the Italian, Eustachius, in 1563. They are noteworthy because they receive the largest volume of blood per weight of any structure in the human body.

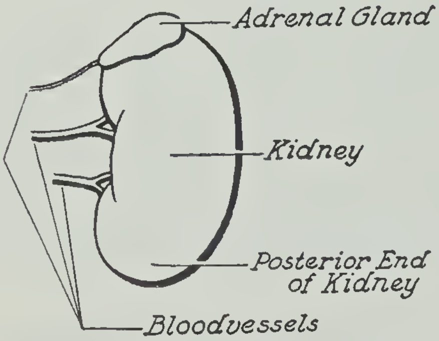

FIGURE 131. Diagram showing the position of an adrenal gland (man).

Adrenal glands. Each adrenal gland is divided into two parts; an outer part and an inner part. The outer part is known as the cortex; the inner part as the medulla. It is with the medulla that we are primarily concerned here, because the medulla secretes the hormone epinephrine (adrenalin). The medulla is intimately associated with the nervous system; in fact, the medulla contains nervelike tissue. The hormone cortin is secreted by the cortex.

Epinephrine. Any excitement, such as that accompanying pain, fear, or anger, may cause the adrenal glands to secrete epinephrine actively. Epinephrine passes into the blood vessels, and first of all into blood vessels of the abdominal region — blood vessels that are associated with the digestive organs. The presence of relatively large amounts of epinephrine in these blood vessels causes their muscular walls to contract. Consequently, blood is kept out of the digestive organs to some extent, at least for the time being. This blood now goes to the muscles of the body, including muscles of the arms and legs. At the same time, the liver is discharging stored glycogen back into the blood in the form of sugar, that may be oxidized to provide energy for muscular exertion. The net result is that the processes of digestion tend to be retarded during moments of excitement, while conditions become more favorable for muscular activity. It is possible that this state of affairs might be of advantage in times of stress.

Epinephrine also speeds up the action of the heart and relaxes the muscles of the blood vessels in the heart wall. This allows more blood to pass through the heart wall and hence makes it possible for the heart to work harder without the danger of serious injury, except in diseased conditions. Dr. J. J. Abel of Johns Hopkins University first isolated the hormone epinephrine in 1897, and it was prepared synthetically in 1906.

Uses of epinephrine in medical practice. It has been found that epinephrine is of considerable value in the practices of medicine and dentistry. For one thing, it can be used to check bleeding in some of the more delicate operations. We recall that epinephrine contracts the muscles of blood vessels, thus tending to stop the flow of blood. It also is mixed with local anæsthetics with good results. When such a mixture is injected into a tissue, much of the blood is forced out of that tissue. This reduces the amount of blood lost. The period of anæsthesia actually is longer than it would be if only the local anæsthetic were used.

Epinephrine has been used to relieve people who are suffering from certain types of asthma, or hives, and to counteract overdoses of insulin. But perhaps its most remarkable use is in connection with the heart. In some cases wherein the heart has ceased to "beat," its contraction can be started again by injecting epinephrine directly into the wall of the left ventricle. Not many cases occur in which this practice is feasible, but it is none the less interesting and remarkable.

Addison's bronze disease. What is known as Addison's bronze disease apparently follows failure of the adrenal glands to function normally. This disease was first described by Addison in 1885. In 1867, Brown-Séquard demonstrated that death followed removal of the adrenal glands.

THE PITUITARY BODY

(Appears to be associated with growth, sexual development, and other processes)

Pituitary body. One of the most interesting glands of the human body is the pituitary body. This structure is about the size of a pea, and is attached to the ventral surface of the brain. It is partially enclosed by one of the bones of the skull. The pituitary body is divided into three regions, known as the anterior lobe, the pars intermedia, and the posterior lobe. The posterior lobe contains nerve elements and acts as a storage place for the secretion of the pars intermedia.

Giantism. The anterior lobe of the pituitary body is thought to produce a secretion which has effects upon growth and sexual development. It is thought that unusually great activity on the part of this anterior lobe during early development results in the production of individuals who are extremely tall — the condition known as giantism. If this lobe becomes unusually active during adult life, the increased activity is associated with thickening of the face, enlargement of the hands and feet, loss of "intelligence," and enlargement of the bones.

Dwarfs. On the other hand, deficient secretion on the part of the anterior lobe (pituitary) is associated with lack of sexual development and small size. Dwarfs are known to have small pituitary glands, at least in some cases.

Pituitrin. The hormone pituitrin has been extracted from the posterior lobe of the pituitary body. This hormone apparently tends to maintain the state of contraction in smooth muscle, and appears to affect the kidneys. It is known to produce a number of effects when injected (hypodermically) into the human body; for instance, it increases the activity of the kidneys.

SOME DIGESTIVE PROCESSES ARE REGULATED BY HORMONES

Hormones and digestion. Some hormones are concerned with the process of digestion in man. For example, there are certain cells in the lining of the stomach which secrete the hormone gastrin. Gastrin is carried to the gastric glands, also found in the wall of the stomach. It stimulates these glands to begin the secretion of gastric juice. Other cells in the duodenum (small intestine) secrete a hormone called secretin. Secretin is carried by the blood, and stimulates the gland cells of the pancreas, liver, and intestines, causing them to begin their secretion. Secretin is first produced when the acid gastric juice of the stomach enters the duodenum with the partially digested food. Thus it will be seen that some of the digestive processes are under chemical regulation to a certain extent.

OTHER STRUCTURES ARE ASSOCIATED WITH THE PRODUCTION OF HORMONES

The spleen. The functions of a number of other structures are less well known. The spleen, for instance, is sometimes considered to be a ductless gland. In man, it lies below the diaphragm, behind and to the left of the stomach. It has been removed from the bodies of animals, apparently without serious results. In the case of man, it has been suggested that the spleen may be involved in one or more of the following processes:

1. The destruction of damaged red corpuscles.
2. Development of red corpuscles in the developing individual.
3. Preparation of hæmoglobin, or storage of this substance.
4. Associated with the reduction of protein wastes to forms that can be discharged by the kidneys.

One interesting fact is known about the spleen, but we are not as yet able to interpret this fact. It is that after a meal the spleen expands gradually for about five hours, and then begins to contract.

The sex organs. Both the testes of the male and the ovaries of the female function to some extent in the production of hormones. In both cases the hormones are thought to play a part in the development of the secondary sexual characters, which distinguish the male from the female. It now appears that the ovaries (female) produce two distinct hormones.

The thymus gland. A structure that is somewhat of a mystery is the thymus gland. It is largest and best developed in children, and begins to decrease in size when the individual becomes an adult. It is a two-lobed gland, lying in the thorax, ventral to the heart, and extending up into the neck region. It appears that children one or two years of age, who have large thymus glands, sometimes die suddenly. Whether or not such deaths are associated with the large thymus glands is not definitely known.

The results of experiments upon the thymus gland have not been conclusive up to the present time. Perhaps future experiments will disclose either that this gland has no important function, or the nature of some function not known today.

The pineal body. The pineal body is a small structure on the dorsal surface of the brain. In early development it contains gland tissue, and it reaches its maximum size in the seventh year of life. After that time it becomes smaller and the glandular tissue disappears. The function of the pineal body also is obscure. It has been suggested that it may secrete a hormone that prevents development of the reproductory organs in early life.

The parathyroids. Somewhat more is known about the parathyroids. These are brownish-red bodies located in the neck region.[1] There are two main pairs. It appears from the results of experimentation upon animals that if the parathyroids are removed there is a marked tendency to develop acidosis. A rigidly contracted condition [2] of the muscles develops. An extract of the parathyroids has been prepared for experimental uses.

[1] Closely associated with the thyroid gland.

[2] This condition is known as tetany.

HORMONES ARE "CHEMICAL MESSENGERS OF THE BODY"

In conclusion, we find that a number of hormones have been identified from the human body, and that their effects are known. In other cases it is suspected that certain structures produce hormones, or certain hormones are associated more or less definitely with various functions. We must remember that this is a relatively new phase of biological study, yet one which has produced amazing results and one in which many more discoveries undoubtedly will be made.

All of the hormones pass into the blood and are carried by the blood to the regions where the effects are produced. Therefore it is not inappropriate to call them the "chemical messengers of the body."

Summary. Most of our knowledge concerning hormones has been developed since the beginning of the twentieth century. We now see that the ductless glands of man and other vertebrates are of great importance in relation to normal activity of the body. The hormones affect many phases of metabolism. In other words, development, growth, and all processes that go on within the adult body are directly or indirectly affected by one or more hormones. Since metabolism represents the use of energy, we may conclude that hormones greatly influence energy transformations.

SUGGESTED ACTIVITIES

Scientific methods

A scientist suspends judgment about questions concerning which he has few facts.

1. With the aid of a microscope, examine a prepared slide which represents a section through the pancreas. Try to locate the groups of cells which make up the islands of Langerhans.
2. Make a chart to illustrate a duct-bearing gland, and a ductless gland. Give examples of each type.
3. Explain the statement that "regions over which glaciers have passed, or in which the drinking water comes chiefly from melted ice and snow, are regions in which goiter is prevalent." Look up the facts about goiter in Switzerland, and in the Great-Lakes region of the United States, and correlate your findings with this statement.

4. Examine the adrenal glands of a dissected frog. They are yellowish-brown, elongated bodies, embedded on the ventral sides of the kidneys.
5. Make an outline diagram of the human body and indicate by means of dots the approximate positions of the following glands: pituitary, thyroid, parathyroids, thymus, pancreas, and adrenals.
6. Examine pictures of abnormalities in man or other animals due to excessive or deficient secretion of various hormones.
7. Construct a chart which tabulates: (*a*) the ductless glands, (*b*) hormones secreted, (*c*) effects produced by the hormones, and (*d*) diseases due to deficiency or excess of hormone secretion.

SUMMARY OF PRINCIPLES

1. Hormones are regulators of metabolism.
2. Hormones are chemical substances which bring about changes within organisms without themselves undergoing a permanent qualitative or quantitative change.
3. Hormones are secreted by certain ductless glands and enter the blood stream as it passes through these glands.
4. Hormones have been found only in higher animals and represent adaptations of high specialization.
5. Thyroxin, which is produced in the thyroid gland, influences the rate of oxidation within the body.
6. Insulin, which is secreted by cells of the pancreas, affects the metabolism of sugars.
7. Epinephrine (adrenalin), which is secreted by the adrenal glands, affects the circulatory and digestive systems, and is used in medicine to stop bleeding and for other purposes.
8. A secretion of the pituitary gland affects growth and sexual development.
9. Some digestive processes are in part regulated by the actions of hormones.
10. The testes, ovaries, and parathyroids of certain vertebrates produce hormones.
11. Other structures such as the thymus, pineal body, and spleen may have functions which are not as yet fully understood.

GUIDE QUESTIONS

1. Name three glands with ducts; three glands without ducts; and one gland which serves both as a digestive and a ductless gland.
2. In what ways does a hormone differ from an enzyme?

3. Name three hormones and state the functions of each.
4. What conditions are caused by (*a*) lack of thyroxin; (*b*) excess of thyroxin.
5. What is a simple goiter and how is it related to (*a*) iodine, (*b*) sea food, (*c*) the thyroid gland?
6. What hormone is used in surgical work to stop bleeding?
7. Discuss the effects of epinephrine upon the human body.
8. Name two hormones associated with digestion. State the function of each.
9. State one fact about each of the following structures: thymus, parathyroids, pineal body.
10. Why are hormones called "chemical messengers"?

BOOKS TO READ

Dorsey, G. A. *Why We Behave Like Human Beings.*
Jennings, H. S. *The Biological Basis of Human Nature.*
Kimber, D. C., and Gray, C. E. *Textbook of Anatomy and Physiology.*
Steiglitz, J. O., ed. *Chemistry in Medicine.*
Stiles, P. G. *Human Physiology.*

CHAPTER XVII

RESPIRATION AND MUSCULAR ACTIVITY

Problems:

1. How is respiration involved in the use of energy in the animal body?
2. What types of muscle cells are present in the human body?
3. How is muscular activity regulated in the body of a higher animal?
4. What common diseases are associated with the respiratory system?

Foreword. Many of us have seen trained athletes running in a long race, or have taken part in such races. We have observed that when the race is close, certain individuals seem to have the strength to go on and win, while others are too exhausted to make the necessary effort. Probably we should say that on the one hand the runner had "conserved his energies," while the exhausted runner had used up his energies in the earlier stages of the race.

Many factors are involved in this situation. From the standpoint of biology, the good runner is trained to run with a certain stride and at a certain pace designed to make the best use of his available energy and physical equipment. Running the race represents the use of energy, through the co-operative efforts of a number of internal systems. The energy must be supplied from certain sources and the waste products which result from muscular activities must be removed.

The tissues of a complex animal body receive food materials from the blood. Such food materials are assimilated by or become included in the protoplasm of the cells. Energy may be liberated by oxidation of the cellular material. It has been noted that oxygen must be supplied to the cells if oxidation is to

By Ewing Galloway, New York.

FIGURE 132A. The finish of a race — an example of the use of energy. Why does a runner become tired?

Acme — P. & A. Photo.

FIGURE 132B. Tennis — one form of exercise.

Two Forms of Exercise.

take place. Maintaining a supply of oxygen is a function of both the respiratory system and the circulatory system. Muscular activity, like any other cellular activity, involves the use of energy. The function of respiration is closely associated with muscular activity.

ANIMALS HAVE VARIOUS ADAPTATIONS FOR RESPIRATION

Oxygen and the circulatory system. Oxygen is obtained either from the atmosphere (air-breathing animals), or from the water, as in the case of aquatic animals such as Hydra, tadpoles, and fishes. In many animals which develop circulatory systems the oxygen is transported to the cells of the body by the blood. In the case of simple animals, whose bodies are composed of a few cells or single cells, oxygen is taken in directly from the surrounding medium, which usually is water.

The respiratory system in man. In the human body, air enters the pharynx either through the nasal passages or through the mouth. It then passes through a slitlike opening, known as the glottis, into the larynx. The latter structure, sometimes known as the "Adam's apple," contains the vocal cords. From the larynx the air passes into the windpipe or trachea, which branches to form two bronchial tubes, one connecting with each lung. Within the lungs the bronchial tubes branch and rebranch until the air is brought into the tiny spaces of lung tissue known as air sacs (or alveoli).

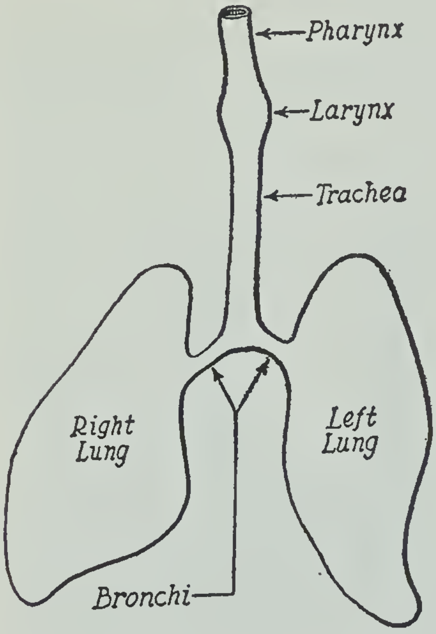

FIGURE 133. Diagram of the human respiratory organs.

The walls of the air sacs contain capillaries, and oxygen now enters the blood, or rather, in the case of man, the red corpuscles of the blood. At the same time the blood discharges carbon-dioxide waste that it has received from the cells of the body.

Breathing. The movements of breathing involve inhalation, or taking air into the lungs, and exhalation, or expelling air from the lungs. When we inhale, muscles contract in such a manner as to cause the diaphragm to be pulled downward and the ribs to be raised. This results in expansion of the lung tissues, and air is drawn into the lungs as a result of this expansion. When we exhale, the diaphragm and ribs return to their former positions and the chest cavity becomes smaller. The lung tissues then become contracted and air is forced out again.

Having reviewed the means by which oxygen is made available to the cells, let us examine the muscular mechanism as it occurs in the human body.

THREE TYPES OF MUSCLE CELLS ARE DEVELOPED IN THE HUMAN BODY

We have studied the partial development of primitive muscle cells in Hydra — cells which are specialized in the function of contraction. And in our study of cells in general we learned that among higher animals three kinds of muscle cells are developed. In all three cases these are cells which are specialized for the function of contraction.

Smooth muscle. In the human body, we find smooth muscle mainly in the walls of the digestive canal, the walls of the veins and arteries, in the skin, and in such structures as the eyes and the bronchial tubes. This type of muscle is composed of elongated cells, each containing but one nucleus. Smooth muscle is not under conscious control and hence sometimes has been called "involuntary muscle." Its movements are relatively slow as compared with those of the other types of muscle.

Skeletal muscle. Skeletal muscle, in the human body, is represented by such muscles as those responsible for movements of the arms and legs. The activity of this type of muscle results from stimulation by the nervous system. It is sometimes called "voluntary muscle."

A skeletal muscle is composed of a number of fibers. Although the muscle itself may be eighteen inches long, the fibers of which it is composed are an inch or less in length and about one five-hundredth of an inch in diameter. Each fiber probably represents a modified cell and contains several nuclei. It is marked by transverse striations, and therefore this type of muscle or fibe.′ is called striated muscle.

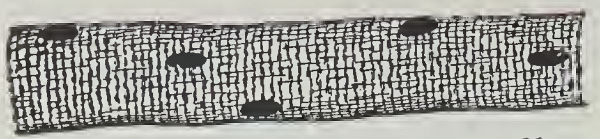

FIGURE 134. A striated muscle fiber.

Cardiac muscle. The third type of muscle found in the human body is called cardiac muscle. This type is found only in the walls of the heart. In appearance it is intermediate between the smooth and striated. The individual cells of cardiac muscle have single nuclei and transverse striations. The interesting thing about cardiac muscle is that it has automatic properties. It should be remembered, however, that the walls of the heart are connected with certain branch nerves. In man, one set of nerves tends to slow down the rate of contraction while another set of nerves tends to stimulate contraction.

AMŒBOID AND CILIARY MOTION

(Represented in many organisms)

Two types of organic activity which involve contraction are amœboid and ciliary movement. Although such movements may not be performed by muscle cells, they are related to muscular activity.

Amœboid motion. Amœba undergoes what is called amœboid movement. Pseudopodia are formed and are involved in the movements of this animal. Amœboid movement, however, is not limited to Amœba. We have given some attention to white corpuscles, such as those found in human blood and the blood of frogs. We find that these cells also undergo amœboid movement. White corpuscles, in the plasma or the lymph, function to some extent as if they were separate organisms living within the body. They ingest foreign matter just as such particles might be ingested by Amœbæ. White corpuscles pass through spaces between cells forming the walls of the capillaries by virtue of the fact that they have the amœbalike ability to change shape.

Amœboid movement represents the results of extension and contraction, or perhaps contraction alone; for the extension of pseudopodia probably results from contraction of the main mass of cytoplasm. This type of movement furnishes one example of the use of energy in the animal body.

Ciliary motion. We have observed that such organisms as Paramecium develop cilia which are employed in the processes of locomotion and ingestion. The activity of cilia is referred to as ciliary movement. Cells bearing cilia are not limited to the lower organisms, for we find such cells commonly in the bodies of higher animals. The passages of the nose are lined with ciliated cells in the case of man. So are the inner surfaces of the trachea and the bronchial tubes.

The function of these ciliated cells in the nasal passages of man is to remove dust particles. Similar ciliated cells are found in the œsophagus of a frog, and they serve to move particles of food toward the stomach. In any case, the principle is the same — ciliary movement results from contraction, and furnishes another example of the use of energy.

WASTE PRODUCTS ARE FORMED AS A RESULT OF MUSCULAR ACTIVITY

Contraction. When the striated muscle cell is supplied with food and oxygen, oxidation occurs and energy is released which may be used in contraction. If enough oxygen is available, the process of oxidation may be complete. A fat, for instance, will be broken down into the nonpoisonous waste products carbon dioxide and water. After the cell has contracted, it appears that oxidation takes place and the cell is prepared for the next contraction.

Fatigue. Now suppose that a number of contractions follow each other rapidly. The cell may not have sufficient food in this case, but it is more likely that there will be a shortage of available oxygen. In such case complete oxidation may not occur and lactic acid, a waste product, accumulates. When the muscle is allowed to rest again, the lack of oxygen may be remedied. One of the most important factors in fatigue is the accumulation of lactic acid in the muscle cells.

Basal metabolism. Every individual has a certain rate at which oxidation takes place in his or her body. This rate is affected by disease, by food, by exercise, and other factors. The rate at which oxygen is consumed when no food is being digested and when the body is at rest is called the rate of basal metabolism. As we noted in the study of hormones, this rate of oxidation is controlled in part by thyroxin.

The diagnosis of thyroid disease is aided by determining the basal metabolism of a person. The details of the method are too complex to relate here. However, we may say briefly that the determination is made by considering the age, sex, and weight of the person, and by measuring the amounts of oxygen consumed or of carbon dioxide produced when the person is at rest.

Necessity of muscular activity. The tendency to activity is one of the fundamental impulses of life. While some persons appear to get along with little exercise, this is the exception rather than the rule. Youthful activity is a spontaneous expression of the life impulse. Games and sports are therefore desirable means of exercising the muscles. In this age of machine work the necessity of muscular exertion for most people is made increasingly less.

Exercise. As a consequence many adults habitually take too little exercise. These habits are opposed to the known principles of life. *Moderate* muscular exercise is necessary for the maintenance of the proper functioning of the heart, the circulation, the lungs, and of the digestive system. Physicians advise, and intelligence demands, that every individual form habits of taking exercise daily. Some sport, such as golf, tennis, swimming, skating, bicycle riding, horseback riding, or hiking, one which can be carried on throughout the period of adult life, may well be adopted by every young person. Do not rely upon cheering in the grandstand for your recreation. Take exercise.

Production of heat. Muscular activity, or oxidation in general, results in the production of heat. In the case of man this heat may be used in maintaining the normal body temperature. If the weather is warm, the heat so produced may represent excess heat, in which case much of it may pass out of the body by way of the blood and the skin. We shall learn more about this process in the following chapter.

IN HIGHER ANIMALS MUSCULAR ACTIVITY IS INFLUENCED BY THE NERVOUS SYSTEM

In such an organism as man, the muscles are to a greater or lesser extent influenced in their contractions by the nervous system. Let us examine the relationship that exists between the nervous system and skeletal muscle.

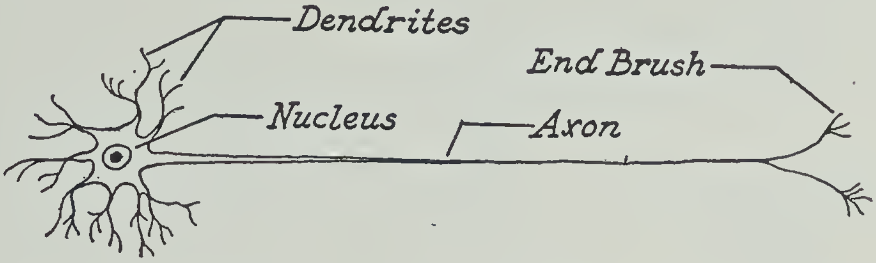

FIGURE 135. Diagram of a nerve cell (motor nerve cell).

The nerve cell. The unit of the nervous system is the nerve cell. (See Figure 135.) As we have noted before, such a cell is specialized for the purpose of conveying nerve impulses. The human nervous system is made up of thousands of these nerve cells. Many cell bodies are located in the brain and the spinal cord. Others are found in various parts of the body. The brain and the spinal cord make up what is known as the central nervous system.

Nerve cells vary in form, depending upon their functions. Each cell has a nucleus and various extensions of the cytoplasm. In the accompanying diagram (Figure 135) you will see that one long process of the cytoplasm is called an axon. This process might also be called a nerve fiber. Other processes, which usually are short and rather thick at their origins, are called dendrites. The functions of both dendrites and axons are to convey nerve impulses toward or away from the cell body. We should keep clearly in mind the fact that nerve fibers are *processes of nerve cells.*

The nerve and nerve fiber. A nerve in the human body consists of a number of nerve fibers which are enclosed within a sheath. Each fiber, in turn, has its own sheath or outer covering. A nerve may be large enough to be seen by the unaided eye, but a fiber from a nerve is microscopic in size. A nervous impulse may travel at the rate of 300 feet per second in the human body; it represents energy rather than matter.

Motor nerves. We may recall that a skeletal muscle is made up of units which also are known as fibers. Probably each fiber of skeletal muscle has the branched ending of a nerve fiber attached to its middle portion. One nerve fiber may give off branches to several muscle fibers. The nerve cell, together with its fiber or axon, and the muscle fibers to which the branches are attached, make up a unit. Such a nerve cell is called a motor nerve cell because it stimulates a muscle fiber or fibers to activity. The unit is referred to as a neuromuscular unit because it involves both nervous and muscular elements.

We now may picture a skeletal muscle as being composed of a number of neuromuscular units. The fibers or cells of the muscle are under control of the motor nerves which branch from the central nervous controls — the spinal cord, and the brain.

Reflex action. Perhaps we can obtain an even better understanding of the relationship existing between the human nervous system and the muscles by considering the case of reflex action. We may have had the experience of touching some hot object with a hand. We jerk the hand away, and we do this "automatically." A moment later, perhaps, we realize that the object touched was hot and capable of burning the hand. This gives us an example of a reflex act — one that is made in response to a stimulus, involves the functioning of the central nervous system, but does not require attention.

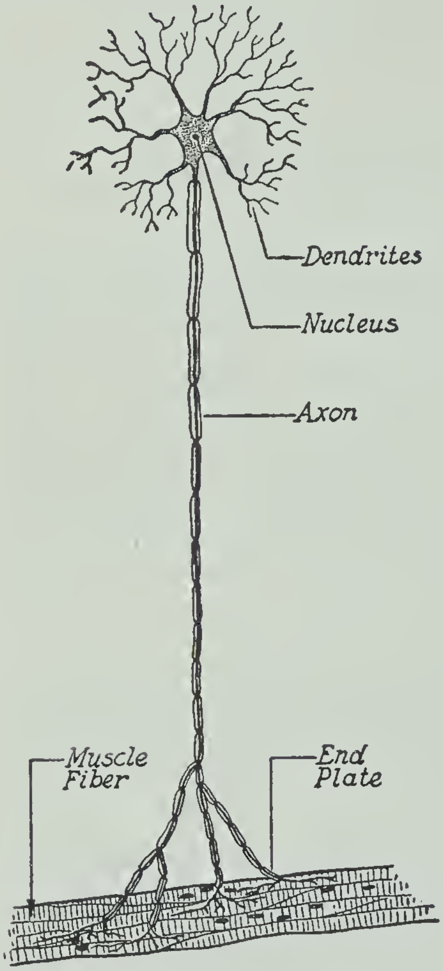

FIGURE 136. Diagram of a neuromuscular unit.

The reflex mechanism. Let us now examine the mechanism responsible for a reflex act. In the first place, a sense organ — perhaps an organ of touch located in the skin — receives the stimulus. In the foregoing case, this stimulus consists of contact with a hot surface. Then a nervous impulse passes along a nerve fiber to the spinal cord, which is an important reflex center. The impulse reaches the processes of the motor cells located in the spinal cord. Then these motor nerve cells send out impulses by way of their axons and branches to the muscles. The result is that the muscles contract and the hand is withdrawn from the hot surface.

Nerve impulses. Impulses traveling toward the central nervous system are called afferent impulses. Impulses traveling away from the central nervous system are efferent impulses.

The cell bodies of the motor nerve cells are located in the so-called gray matter of the spinal cord. Afferent fibers enter the spinal cord by way of the so-called dorsal roots. Efferent fibers leave the spinal cord by way of the ventral roots. The gray matter of the cord contains a good many cell bodies, while the outer white matter is made up largely of nerve fibers.

In higher animals, such as man, some reflexes are regulated by cells in the brain as well as by cells in the spinal cord. Certain parts of the brain are recognized as being reflex centers.

Muscles and the nervous system. From the foregoing statements, it will be seen that the muscles of the human body are associated in their activity with the nervous system. This is true, even in the case of cardiac muscle. The nervous system, like other systems, is involved in the use of energy in the animal body.

A NUMBER OF DISEASES ARE ASSOCIATED WITH THE ORGANS OF RESPIRATION

A number of very important diseases involve the human respiratory system. One of these is tuberculosis. This disease is also found among birds, hogs, and cattle, but the bird type of tuberculosis apparently is not transmitted to man.

Tuberculosis. Human tuberculosis is not confined to the lung tissues, although tuberculosis of the lungs (consumption) is a common form of the disease. But other structures of the body, such as the bones, kidneys, skin, liver, spleen, and some of the glands, may become infected. Tuberculosis of cattle may be transmitted to man through the agency of milk. Apparently it does not produce tuberculosis of the lungs in man, except possibly in rare cases, but it may produce tuberculosis in other tissues of the body. One purpose of milk Pasteurization is to prevent human beings from becoming infected by milk which may have come from tubercular cattle.

Common colds and influenza. The common colds are among our most annoying ailments. Probably several types of these colds exist, and many attacks are complicated by secondary invaders, which affect the tonsils or other structures. The organism or organisms that cause common colds are not definitely known, but filtrable viruses (see p. 495) are suspected. The body recovers from most colds because of its natural defenses. Now and then, however, a neglected cold ends in a case of pneumonia. One of the best ways to deal with a cold is to stay in bed. When this is done, recovery usually is rapid, and there is less chance to spread the disease. Influenza is a much feared disease when it appears in virulent form. The last great epidemic swept over our country in 1918 and 1919.

Pneumonia. Lobar pneumonia has been a great killer of the modern world. It is caused by the pneumococcus, a bacterium of which thirty-two types are now known. Germs of the coccus variety have been a great medical problem until recent times. A few years ago the German scientist, Gerhard Domagk, tried out a sulfanilamide compound (prontosil) on mice that had strep infections. Since that time over a thousand of these compounds have been prepared. One of them, sulfapyradine, has been effective in treating pneumonia and some other diseases.

Suffocation. One type of suffocation that is associated with the use of the automobile is produced by inhaling carbon-monoxide gas. This gas is present in the exhaust fumes of motors in concentrations up to ten per cent. If the motors are running in the open air, the carbon monoxide soon diffuses in the air. But if the motors are in confined quarters, such as closed garages, the carbon monoxide is likely to be inhaled with fatal results. This gas is colorless and practically odorless. It combines with hæmoglobin very readily, preventing oxygen from so doing. In a short time the cells of the body are deficient in oxygen, the victim becomes unconscious, and in a few minutes the heart ceases to beat. Even ordinary illuminating gas, which contains from six to forty per cent of carbon monoxide, may be deadly when a relatively small percentage is present in a confined space.

MUSCULAR EFFICIENCY

(In the complex animal, muscular efficiency depends upon the co-operative work of several systems)

Summary. In reviewing the foregoing pages we find that muscular activity is made possible through the combined work of several systems in the body of the specialized animal. The supply of food depends upon the activities of the digestive and circulatory systems. The necessary supply of oxygen is provided by activities involving the respiratory and circulatory systems. The nervous system to a greater or lesser extent regulates muscular activity. Even the activities of ductless glands may indirectly affect muscular contraction. Finally, the blood removes wastes from the cells. We have observed that the waste carbon dioxide is eliminated in the course of respiration. In a future discussion we shall see that the kidneys and associated organs are concerned in the elimination of liquid wastes which are formed when muscular activities occur. It becomes increasingly evident to us that normal activity of the muscles depends upon the functioning of a number of systems within the body of a higher animal.

SUGGESTED ACTIVITIES

Scientific methods

A scientist is skeptical of assertions which are not supported by facts.

1. After consulting the reading references at the end of this chapter, prepare a chart showing the relationships of the various respiratory structures in the human body.
2. With the aid of a microscope or microprojector, examine a section of lung tissue. Identify in particular the alveolar spaces, and cross sections of blood vessels.

3. Determine how many times per minute each member of the class inhales and exhales when sitting quietly in a chair. Determine whether or not this rate is affected by mild exercise.
4. Demonstrate that exhaled air contains more carbon dioxide than does normal air. Shake limewater in a bottle of air, and then in a bottle containing exhaled air. A milky-white color of the liquid indicates the presence of carbon dioxide.
5. By consulting the reading references at the end of this chapter, determine the nature of a respiration calorimeter. Report experiments and findings which involve the use of this apparatus. What is "basal metabolism," and how is it determined?
6. With the aid of the microscope, examine prepared slides of different kinds of muscle tissue, such as smooth, striated, and cardiac.
7. With the aid of the microscope, observe amœboid movement (Amœba), and ciliary movement (Paramecium), if this has not been done in previous exercises.
8. Demonstrate reflex actions, such as the "knee jerk," and contraction of the pupil of the eye when an individual comes from a darkened room to a brightly lighted room.
9. After consulting the reading references at the end of this chapter, prepare a chart of a neuromuscular unit, and be able to explain its function.

SUMMARY OF PRINCIPLES

1. Respiration and circulation are necessary processes in supplying oxygen and fuel for the energy release necessary to muscular activity.
2. Three types of muscle cells appear in man: smooth, striated, and cardiac.
3. Movement in some single cells is achieved by the adaptations known as pseudopodia, cilia, or flagella.
4. Movement is the result of energy released by oxidation of food (protoplasm) material.
5. Muscles are controlled by the nervous system — some are "voluntary" and some "involuntary."
6. A number of diseases are associated with the respiratory system of man.
7. Muscular efficiency is the result of the co-operative work of several systems of the animal body.

GUIDE QUESTIONS

1. Describe the parts of the respiratory system of man.
2. Describe each of the three types of human muscle cells.
3. What is meant by amœboid movement? By ciliary movement? Discuss examples of these types of movement in the human body.
4. Explain how energy for activity is obtained and utilized by muscles.
5. What are the products of oxidation in the muscles?
6. Explain the term "fatigue."
7. What is a neuromuscular unit?
8. Give an example of "reflex action."
9. Discuss three diseases of the respiratory system.
10. Name several co-operating systems involved in muscular activity in man.

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CHAPTER XVIII

REMOVAL OF WASTES

Problems:

1. How are wastes removed from the animal body?
2. What common diseases are associated with human excretory organs?

Foreword. In the preceding chapter we noted briefly some biological problems which confront an athlete who is taking part in a race. We now are able to answer some of the questions which arise from this situation.

The runner is using energy. The energy is obtained by his body through the medium of food, which is digested, absorbed by the blood, and conveyed to the cells — including muscle cells — where it is assimilated. Oxygen is made available to these same cells through the combined work of the respiratory and circulatory systems. The oxygen is necessary to oxidation and the release of the energy which makes muscular contraction possible.

Runners are trained to run in a certain manner and at certain rates of speed. Here the nervous system is prominently involved in producing a co-ordinated response on the part of the muscles. We learn from observation that some individuals have better muscular co-ordination than do others. As one coach said about a certain athlete who did not seem to be improving in his technique: "He certainly is a remarkable runner, but he runs too long in one place."

We also have learned that a runner, or for that matter anyone taking part in muscular activity, becomes fatigued under certain conditions. We have noted that fatigue often is due to a shortage of oxygen in the muscle cells, and the accumulation of the waste material known as lactic acid. Removal of waste is, then, very important if a high rate of muscular efficiency is to be maintained. The discussion which follows is related to this phase of the use of energy in the animal body.

CARBON-DIOXIDE WASTE IS DISCHARGED IN RESPIRATION

Respiration and excretion. Several times in preceding discussions we have noted how closely the functions of several systems in the animal body are related to each other. Respiration and excretion have such a relationship because it is in the process of respiration that most of the carbon-dioxide waste is discharged. This gaseous carbon-dioxide waste is the most prominent product of metabolism in the animal body.

Removal of carbon dioxide. In studying Amœba we found that respiration involved an exchange of carbon dioxide and oxygen through the cell membrane. Carbon dioxide was discharged from the cell. Essentially the same process occurs in the case of an earthworm, except that the outer layer of the body wall acts as a respiratory membrane. In the amphioxus we find that gills provide for the exchange of gases. In the leopard frog we observe a change from gills to lungs within one life cycle. The air breather, as illustrated in the study of the adult frog or man, effects the exchange of gases through the medium of lung tissue.

Exchange of gases. In all of these cases, the fundamental principle remains the same. An exchange of gases occurs through the medium of some membrane or tissue. In previous discussions we have learned how oxygen, having entered the body, is used by the cells in releasing energy through oxidation. At the same time, the waste carbon dioxide is removed from the body. This removal of carbon dioxide is a necessary part in the general process of metabolism.

WATER SERVES AS A CARRYING MEDIUM IN THE DISCHARGE OF LIQUID WASTES

Water in relation to wastes. One of the important functions of water within the organism is to provide a carrying medium for liquid wastes, such as those which result from the oxidation of proteins. In Amœba we found that such wastes are probably discharged from the cell by way of the contractile vacuole. But in the more complex bodies of an earthworm and the amphioxus special structures remove the liquid wastes from the body cavities.

Kidneys. In studying a frog we learned that liquid wastes were removed from the body by way of the kidneys. That is, the liquid wastes were collected from the various parts of the body by the blood, and were removed from the blood by the kidneys. Then such wastes were discharged to the exterior. Essentially, this is what occurs in the case of man.

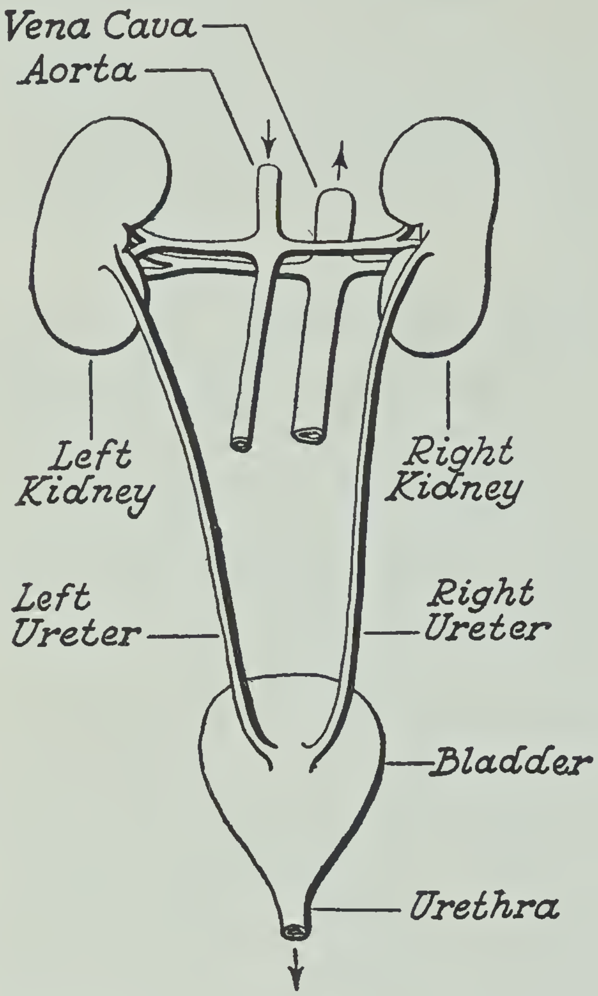

FIGURE 137. Diagram of the human kidneys and associated structures (dorsal view).

The human kidneys. All of the blood passes through the human kidneys within a rather short period of time. Each kidney is made up of a mass of tiny tubelike structures called renal tubules, which collect the liquid wastes from the blood and discharge them into a common space or cavity within the kidney. From this cavity a duct, known as a ureter, conducts the liquid waste or urine to the bladder. There are, therefore, two ureters; one extends from each kidney to the bladder. The bladder is an organ in which urine is collected and from which it passes to the exterior through a duct known as the urethra.

Urine. Urine (man) is composed of water and waste substances. Some seven eighths of the nitrogen in protein food eventually becomes waste in the form of urea. Urea is formed in the liver from the products of protein oxidation occurring in the cells of the body. Then it is conveyed by the blood to the kidneys, and becomes a part of urine. Other protein wastes, such as uric acid, sulphur, and phosphorus, are present in urine, but in smaller quantities. Common salt also appears as a waste in urine.

Water and the urine. The quantity of the human urine is subject to variation, depending upon a number of factors. In the first place, the amount of water taken into the body is of importance. A good deal of this water may be discharged as perspiration through the skin, and thus reduce the amount of urine. In hot weather, however, it is probable that more than an average amount of water will be consumed. This will tend to offset loss of water from the body through the medium of perspiration. But in hot weather or after sustained exercise we may expect shrinkage in the amount of urine unless the intake of water is increased.

Color of urine. The color of urine is due to the presence in it of substances that come from the liver and are related to the coloring matter of bile. When only a small amount of water is available, the wastes in the urine are more concentrated, and consequently the color is darker.

Amount of waste in urine. In the case of man, the amount of nitrogen in the urine usually about equals the amount of nitrogen that is taken into the body in the form of protein foods. During growth, however, or recovery from disease, or following a period of fasting, a larger amount of nitrogen will be retained by the body. Such nitrogen as is retained probably is in the form of proteins that are necessary to the building or restoration of tissues. It is interesting to note that muscular activity is not followed by a marked increase in the amount of nitrogen wastes in the urine. This is significant in view of the fact that muscle cells contain large amounts of protein. Apparently normal activity of these cells does not result in a destruction of any great amount of their substance.

Work of the kidneys. Probably the human kidneys are most severely taxed if they have to remove a maximum amount of waste when a minimum amount of water is available for purposes of solution. A maximum amount of waste would be present following the eating of unusually large amounts of protein foods. An abnormally large amount of salt in the diet also would increase the amount of work to be done by the kidneys. Therefore, from the standpoint of making the work of the kidneys easier, one should not eat too much protein food and salt, and should drink plenty of water.

Protein wastes result from metabolism or energy changes. Their removal from the body, like the removal of carbon dioxide, represents the process of excretion, and is part of the general process which involves the use of energy.

EXCESS HEAT AND SOME WASTES ARE ELIMINATED IN PERSPIRATION

Perspiration. In previous studies we have noted that perspiration is related to the process of excretion. In the human body the process of perspiring is accomplished through the action of the sweat glands which are located in the skin and the tissues which lie beneath the skin. Under ordinary circumstances this perspiration evaporates rapidly. However, following exercise, or in hot weather, it may not evaporate as rapidly as it is excreted.

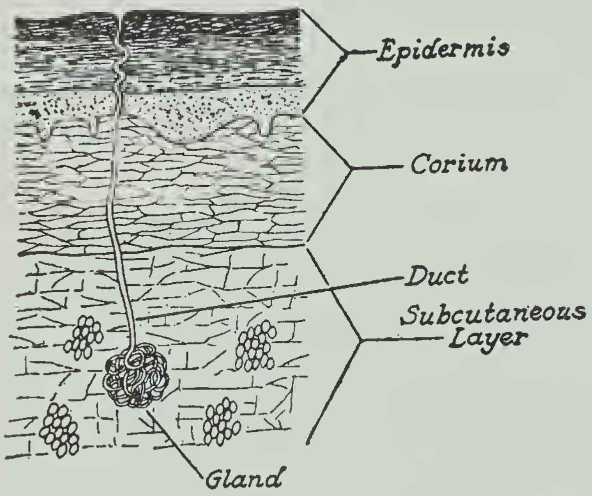

FIGURE 138. Diagram of a sweat gland. What would be the effect of dirt in the opening of this gland?

Wastes in perspiration. The idea that perspiration contains a large amount of waste is erroneous. In the case of the healthy human body about ninety-eight per cent of perspiration consists of water. The other two per cent is made up of wastes such as urea, salts, fatty acids, and carbon dioxide.

Function of perspiration. The principal function of the act of perspiring, in normal health, is to remove excess heat from the body. This excess heat has been liberated in the oxidation process. In the evaporation of a gram of water about one half of a calorie of heat is taken from the system. In a diseased condition, however, in which the kidneys fail to perform their normal functions, relatively more waste material may be present in perspiration.

THE EXCRETION OF SOLID WASTES

Solid wastes. The colon (man) receives the solid waste material remaining after digestion and absorption have occurred higher up in the digestive canal. This solid waste contains the undigested fiber as well as some partly digested materials. Unabsorbed water and bile are also present. The waste is pushed along by muscular contraction and is excreted by way of the rectum. Careless or irregular habits of excretion of this solid waste may lead to serious disturbances. Constipation is a very common ailment. This condition may in turn lead to disordered digestion. Proper hygiene requires that this solid waste be habitually removed once each day. To avoid constipation, physicians recommend regularity of habit, moderate exercise, the drinking of six glasses of water each day (one before breakfast), and abundance of fresh fruits and vegetables in the diet. These measures will assist the "lazy colon" to function.

A NUMBER OF DISEASES MAY INVOLVE THE ORGANS OF EXCRETION

Diabetes and the urine. Now and then we encounter people who have the disease diabetes, and learn that they must take regular doses of insulin. We may also learn that one early indication of the disease is the presence of sugar in the urine. In this disease the urine also contains certain acid wastes in abnormally large amounts. Although diabetes affects the process of excretion, the disease really is caused by failure of certain cells in the pancreas to secrete the hormone insulin.

Sugar in the urine. The presence of sugar in the urine does not necessarily indicate that one's health is threatened. Occasionally, after a period of emotional strain, quantities of sugar may appear in human urine. During periods of stress the liver may discharge some of its stored glycogen which appears as sugar in the urine. It is merely a temporary condition in most cases.

Inflamed conditions of the kidneys. Since the human kidneys remove liquid wastes from the blood, it is clear that their well-being is a matter of great importance. Under certain conditions the kidneys may become inflamed.[1] Various poisonous substances may serve to produce such an inflammation. It also may be a result of some diseases, such as scarlet fever, tonsillitis, and typhoid fever. Or inflammation may result from severe exposure. First attacks brought on by such causes are often acute. Fortunately, in many cases recovery occurs if the cause is removed. If recovery does not occur, a chronic (continuous) phase of this condition may be developed. Or a chronic inflamed condition may result from a gradual hardening of the kidney tissues. To some extent this hardening is similar to and associated with the hardening of the arteries which occurs in old age.

Summary. In conclusion, we have seen that when cells carry on energy changes various waste substances are formed. One of these is carbon dioxide, which is removed from the body in the process of respiration. Protein wastes form another group. In the human body protein wastes are changed into urea largely in the liver, and urea is removed from the blood by the kidneys. Urea is the principal waste substance in urine. Heat energy is released in oxidation. Excess heat is removed from the human body through the medium of perspiration. Solid wastes are discharged by way of the rectum. We see in all of the excretory processes a phase in the use of energy. Oxidation is necessary to energy transformations, and waste products which result from oxidation must be removed from the body.

SUGGESTED ACTIVITIES

Scientific methods

A scientist always tries to state his problems very definitely.

1. Examine the structure of a kidney. Note the blood vessels which connect with this structure, and the ureter through which liquid waste is removed.
2. Prepare a table in which you compare the structures involved in the discharge of liquid wastes in Paramecium, Planaria, an earthworm, amphioxus, a frog, and man.

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[1] As in nephritis, or Bright's disease.

3. With the aid of a microscope, examine a section of kidney tissue (frog suggested). With the aid of the instructor, note how cells are arranged to form the "renal tubules."
4. Outline an experiment to show that both carbon dioxide and water vapor are excreted by way of the human lungs (see page 298). Demonstrate this to the class if the instructor is willing.
5. After consulting the reading references at the end of this chapter, explain the importance of excretory products in the lives of organisms living in a balanced aquarium.
6. With the aid of a microscope, examine a section of skin tissue which shows sections through sweat glands (demonstration).

SUMMARY OF PRINCIPLES

1. Carbon dioxide, a gaseous waste, is eliminated from cells in respiration.
2. Urea is a nitrogenous waste resulting from the metabolism of proteins.
3. Water is the medium in which most liquid waste is excreted.
4. Urea is removed from the bodies of higher animals in the blood stream, from which it is extracted and excreted by the kidneys.
5. Perspiration is largely an adaptation for regulating body temperature.
6. Serious diseases result from improper functioning of excretory organs.

GUIDE QUESTIONS

1. What waste products of metabolism are (*a*) gaseous, (*b*) liquid?
2. Through what process and by what organs is carbon dioxide excreted in man?
3. What is the relationship of the liver to urea?
4. Through what organs is urea excreted?
5. What functions does water serve in excretion?
6. What is the chief function of perspiration? Explain.
7. Discuss a disease which results from improper functioning of the excretory organs.

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UNIT IV

ADAPTATIONS OF BEHAVIOR AND STRUCTURE

IN THE previous unit we have studied some of the ways in which energy is used in the plant or animal body. Let us now turn our attention to some special phases of structure and function which also involve the use of energy. We refer here to adaptations.

Previously, we have learned that plants and animals live in a changing environment. Many organisms adjust their behavior to changes in the environment. Such adjustments of behavior may be called adaptations. Organisms possess structures which enable them to survive under certain conditions of life. Such structures are also known as adaptations. Adaptations, then, may refer either to behaviorisms or to structures. In fact, most so-called adaptations involve elements of both structure and behavior.

We have learned that protoplasm is sensitive. Let us now study the behavior of lower organisms. How do these organisms react to the various forces in their environments? What is a "stimulus," and what is a "response"? What kinds of responses are made by organisms that do not possess nervous systems?

Adaptations of behavior are more complex among the animals that possess well-developed nervous systems. Such animals possess special sense organs. They also have special nerve centers such as spinal cords and brains. We shall wish to learn something about reflexes, instincts, memory, intelligence, and habit. What are the factors which influence the behavior of higher animals, and of man?

All organisms exhibit adaptations of structure and behavior. In some cases these adaptations are rather striking, in other cases they are commonplace. The difference, however, is in degree rather than in kind. We shall not have sufficient space to consider all adaptations. We shall, however, be able to study some of the special types. Some of these adaptations have to do with obtaining food, or securing protection from the attacks of enemies. Others enable organisms to live in special kinds of habitats. Some adaptations represent adjustments to changes in the environment.

CHAPTER XIX

STIMULI AND RESPONSES

Problems:

1. What is a stimulus?
2. What is a response?
3. Are responses limited to changes in behavior or may they involve changes in structure?
4. Why may two cells respond in different ways to the same stimulus?
5. Do organisms which do not have special nerve cells respond to stimuli?

Foreword. It often is interesting to observe the behavior of such simple animals as Paramecium. Let us suppose that we have placed a drop of material from a culture containing these animals upon a glass slide. We have covered it with a cover glass, and are viewing the result with the aid of a microscope. A world that is unknown to many people is unfolded before our eyes. Unseen particles of dead organic matter and particles of inorganic matter are now visible, in fact, quite large. If our culture contains Paramecia, we may see these animals swimming about vigorously, propelled by their actively moving cilia. Their lives depend upon receiving and responding to stimuli of various kinds.

PLANTS AND ANIMALS RESPOND TO STIMULI

If we follow the actions of a single Paramecium we may observe that it comes in contact with some solid object, such as a bit of inorganic material. Perhaps the organism now moves away in another direction. What has happened in terms of our present study? Encountering the solid mass in the water has acted as a stimulus to the organism; the organism has responded by moving off in another direction. Even simple animals such as Amœba and Paramecium indicate by their behavior that they are sensitive (irritable [1]). They respond to a variety of stimuli. We note that a stimulus may be an encounter with some solid object. It also may be other things or forces, such as change in environment, a change in the chemical condition of the water, the presence or absence of light, and many other factors.

Stimulus-response. The terms "stimulus" and "response" have been referred to from time to time in previous discussions. We have learned that the green leaf turns toward the light as a response to the stimulus of light. We noted that root growth was affected by the presence or absence of water, and by the force known as gravity. Since environments are always changing, we are not surprised to know that plants and animals are continually making responses of one kind or another.

A stimulus is not always a force or condition which is outside of the organism. Many stimuli are internal. Consider, for instance, the stimulus known as hunger. Muscles in the wall of the human stomach contract to produce the so-called "pangs of hunger." The response may be to obtain food as soon as possible. Such a response represents a change in behavior.

Another kind of response sometimes results from certain stimuli. When a boy chops wood, or uses a golf club or baseball bat for the first time, he may find that the skin on the palms of his hands becomes blistered. Later on, the skin may harden and become thickened at certain points. A response has been made to the stimulus of rubbing. Protective calluses have been formed. We learn from this example that a response may be a change of structure. It is quite possible that a response may involve both change of structure and change in behavior.

MANY RESPONSES ARE SIMPLE AND MECHANICAL

Tropisms. Up to this point we have considered responses in general. Let us now turn our attention to certain kinds of responses which are known as tropisms. We shall consider tropisms to be machinelike responses to certain stimuli, in which the body of the organism is oriented — its position changed — with relation to the stimulus. Usually a tropism involves response by the whole organism, or by a large part of its body. Tropisms are simple, mechanical types of responses, which do not involve intelligence.

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[1] Irritability has another meaning — the quality of being easily provoked or angered. This, however, is not the meaning assigned to the word as it is used here.

In tropisms the response is closely associated with the stimulus. A certain stimulus results in a more or less unvarying type of response. One school of thought holds that the behavior of a simple animal like Paramecium represents nothing more than a series of tropisms. Another viewpoint suggests that many of the actions of Paramecium, when swimming about in the water, represent a "trial-and-error" method of selecting a favorable environment. We should remember that while Paramecium is small and relatively simple, it is not the simplest form of life by any means. Its behavior appears to be as complex as the behavior of some many-celled animals. Many of the responses of simple animals are regarded as being tropisms.

Some responses of complex animals have been considered as series of tropisms by certain biologists. In one of Jaques Loeb's experiments, fish of a certain kind were placed in a tank of water which was strongly illuminated at one end, and dark at the other. The fish turned and moved toward the strong light. They pushed their heads against the glass, and remained that way until death overtook them. Neither the presence of food, nor other stimuli, served to overcome the response to light. In this example it will be noted that the entire body of the animal is involved in the response. The response shows no guiding intelligence, and even starvation does not prevent the animal from making the response.

Tropisms of plants. Many of the responses made by plants may be regarded as being tropisms. For instance, it is a familiar fact that green leaves turn so that their upper surfaces tend to be at favorable angles to the source of sunlight. In this case we see that a portion of the body has been oriented or changed in position with respect to the stimulus. Not always do we find the leaves arranged at the most favorable angles with reference to the light, but there is an evident tendency toward this result. In dim light, most plants develop longer stems than in bright light. Nasturtiums may be raised under different degrees of illumination to illustrate this fact.

The fact that green leaves turn toward the light is of importance in the process of food making. The rate of food manufacture and of growth, and the formation of chlorophyll are related to the stimulus of light. It is thought that the formation of chlorophyll may represent a chemical change that is induced by the energy of light. Movements of leaves also may be due to water relationships of the cells, and to other conditions, as well as to light stimuli. In such cases they might not be classed as tropisms. But leaves and flowers do respond in definite ways to the stimulus of light.

In experimenting with seedlings we learned that roots grow toward the earth under normal conditions. The same plants and the same experiments show that stems normally grow in the opposite direction from the pull of gravity. These responses are tropisms. We also have learned that the presence or absence of water may provide a stimulus which results in responses on the part of plants. Roots are influenced in development by the presence of water in the soil. Here again we have the tropism type of response. In various species of plants and animals tropisms may represent responses to stimuli of chemicals, temperature, light, pressure, gravity, and water.[1]

Other mechanical responses of plants. Some responses of plants are of a somewhat different nature. While they are simple and mechanical, they do not involve change in the position of the body with respect to the stimulus. For instance, the stomata of leaves respond to the stimulus of turgor (see page 233). When certain cells of a green leaf are filled with water (turgid) the stomata open. When the turgor pressure is low the stomata close. Water vapor in the surrounding air decreases the rate of evaporation; the stomata also respond to this stimulus. Leaves may curl up when affected by the stimulus of heat, or dry air, or both. Probably many of the responses made by plants are dependent upon changes in turgor pressure which are induced by one or more stimuli. We may regard these as being simple, mechanical responses.

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[1] Corresponding scientific names are given to these responses, such as hydrotropism (response to water), phototropism (response to light), thigmotropism (response to touch), chemotropism (response to chemical agents), and geotropism (response to gravity).

Our study of a Venus's-flytrap showed that the leaf blades closed when insects stimulated the little hairs on the leaves. Another unusual plant, Mimosa, which may be seen in greenhouses or in botanical gardens, is very sensitive to touch. Any one of its leaflets will fold up if touched lightly. If a harder blow falls upon the leaf, the latter may droop. Students of botany tell us that here again turgor pressure is involved in the response. These are, of course, mechanical types of responses.

Certain parts of many plants appear to be sensitive. The tendrils of some plants, such as grapes or sweet peas, are said to be so sensitive that the touch of a fine silk fiber, so light that your tongue would hardly detect it, is sufficient to cause a curling of a tendril.

Positive and negative responses. With regard to responses in general, we may say that a response is positive when the organism is attracted toward the stimulus. Thus the moth, which is irresistibly drawn toward a light, makes a positive response. When the organism avoids the stimulus, the response is said to be negative. A protozoan which moves out of a brightly illuminated area of water makes a negative response to the stimulus of light.

What is stimulus conduction? [1] We have yet to explain how stimuli affect the protoplasm of cells, and how they are transmitted or conveyed from cell to cell. Delicate measurements indicate that conditions of energy balance between the inside and outside of cell membranes are altered by changes outside of the cell. Heat, light, pressure, water, food materials, and other factors may disturb conditions within the cell. In other words, such factors act as stimuli. A stimulus sets up a *train of energy changes* passing from cell to cell, which represents stimulus conduction.

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[1] Refers to *conduction of stimuli*, as here used; not to be confused with conduction of water and food materials in plants.

Why are responses different? When a bean germinates, the root system grows downward and the stem grows upward. These are respectively positive and negative responses (in this case tropisms) to the stimulus of gravity. But why should this difference exist? The answer we might make is that the cells of the developing root system and the cells of the young stem probably differ as to their internal conditions, including the type of protoplasm which they contain. In both cases the stimulus of gravity is the same, but it results in very different responses, because the cells were of different types. Thus we see that a given stimulus may affect various cells in various ways. One cell may respond to a certain stimulus, another type of cell may respond in a different fashion, and a third type may not respond to that stimulus at all.

Do plants have nerves? Let us not think that all responses of plants and animals are fully understood, even in the cases of simple responses. Much remains to be studied and explained. We may suggest that when we touch a Mimosa leaf the stimulus sets up a series of energy changes which pass from cell to cell. This is the probable mechanism of stimulus conduction in plants. The mechanism of response probably involves turgor changes within certain cells. It should be noted here that plants do not develop special nerve cells or nervous systems. Among animals, many cells which are not special nerve cells respond to stimuli. Nerve cells are cells which are specialized for the function of conducting impulses. Apparently all cells of plants and animals respond to stimuli to some extent, but not all to the same stimuli.

Complex responses. In the foregoing discussion we have been concerned largely with the simpler types of responses, including tropisms. We should not get the impression that all responses are of simple type. On the contrary, many responses, and especially those made by the higher animals, are very complex. We shall turn our attention to some of the more complex responses in the next chapter.

Summary. In conclusion, we have noted that all organisms are irritable. They receive stimuli and make responses. Stimuli may come from without the body of the organism, or they may originate within the body of the organism. Responses may consist of changes in behavior, or changes in structure, or changes in both behavior and structure. We learn that some purely mechanical responses of an entire organism or a major part of an organism, which change the position of the body [1] with respect to the stimulus, are called tropisms. Some of the responses made by animals and plants are of this type. Plants and animals also make other simple, mechanical responses. Different cells may respond in different ways to the same stimulus. Plants do not have special nerve cells or nervous systems. But many cells, among both plants and animals, which are not special nerve cells, are sensitive to stimuli of certain kinds. All movements of plants and animals represent a series of stimuli and responses. Life is a complex chain of responses to stimuli.

SUGGESTED ACTIVITIES

Scientific methods

A scientist is patient and persistent.

1. Make a "pocket garden" and germinate some radish seeds. Demonstrate for the class that roots respond in development to the force of gravity.
2. Place a living Hydra in a watch glass full of water. Using the point of a dissecting needle touch the end of a tentacle and observe the response. How much of the body is involved in the contraction which occurs? Wait until extension of the body has taken place, then stimulate some other region, such as the body column. By repeated trials attempt to determine which part or parts of the body are most sensitive to touch stimuli. Discuss the type of response which occurs in these cases.
3. With the aid of the compound microscope or a microprojector, observe the behavior of some living Paramecia. Record and discuss some of their responses to stimuli. Stimuli may include contact with particles of solid matter, the presence of a brightly lighted area, contact with chemical substances such as a grain of salt dropped in the water, and other things.
4. If a sensitive plant (Mimosa) can be obtained from a greenhouse, or raised from a seed, perform the experiments suggested on page 313.
5. After consulting the reading references at the end of this chapter, prepare a report on "behavior of the lower organisms."

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[1] Or some large part of the body.

6. Devise an experiment to determine whether some flower, such as a dandelion, or morning-glory, opens or closes under the influence of light, heat, or other stimuli.

SUMMARY OF PRINCIPLES

1. Organisms are irritable and they respond to stimuli.
2. Stimuli may originate outside of the body or may come from within the body of an organism.
3. Responses may involve changes in behavior or structure, or both behavior and structure.
4. Some simple, purely mechanical responses, usually having to do with change of position, that involve the whole, or a large part of an organism, are called tropisms.
5. Some simple responses made by animals, and some responses made by plants, may be called tropisms.
6. Tropisms may occur in response to stimuli of light, temperature, gravity, chemicals, pressure, water, and other things or forces.
7. Different cells may respond in different ways to the same stimulus.
8. Plants do not develop special nerve cells, or nervous systems.
9. Life itself consists of a series of responses to stimuli.

GUIDE QUESTIONS

1. What special life function is involved in responses to stimuli?
2. Define (*a*) stimulus, (*b*) response.
3. Are all responses equally simple or equally complex?
4. What is a tropism? Give an example.
5. Discuss two stimuli to which roots respond in their development.
6. Describe the behavior of Mimosa, which gives it the name "sensitive plant."
7. What are two responses of green plants to light?
8. What is meant by "stimulus conduction"? Is this possible in the body of an organism which does not develop a nervous system?
9. Do all cells respond in the same way to a given stimulus?
10. Are all responses of the tropism type?

BOOKS TO READ

Allee, W. C. *Animal Life and Social Growth.*
Bouvier, E. L. *The Psychic Life of Insects.*
Newman, H. H. *Outlines of General Zoology.*
Plath, O. E. *Bumblebees and Their Ways.*
Washburn, M. F. *The Animal Mind.*
Weed, C. M. *Insect Ways.*

CHAPTER XX

COMPLEX BEHAVIOR

Problems:

1. Are all responses tropisms?
2. Are responses of animals which have nervous systems different from those of organisms which do not have nervous systems?
3. Are any adaptations related to responses?
4. Is a response the simple effect of a cause?
5. What are reflex acts?
6. Are there such things as "instincts"?
7. What is memory?
8. When can we say that an animal is intelligent?

Foreword. Suppose that you are sitting at a table in your home trying to study. The printed page is a stimulus to your eyes. You respond by reading, and perhaps by writing some notes on a piece of paper. When you write as far as the edge of the paper, this stimulates you to stop and begin writing on the line below. Perhaps a radio is operating in another room. A sudden burst of sound stimulates you to stop reading or writing for the moment, and to listen to the radio. After a time a draft from an open window may cause you to feel cold. This is a stimulus to which you may respond by sneezing, or getting up to shut the window, or perhaps by putting on a jacket.

MANY ANIMALS DEVELOP NERVOUS SYSTEMS

In the foregoing example you have received a number of stimuli through the medium of what are called special sense organs. The eyes are special organs having to do with the sense of sight. The stimulation of sound is received through the medium of another pair of sense organs — the ears. You become aware of a cold draft because of special nerves which have endings in the skin. Likewise, you might detect an odor of cooking food through the medium of the special nerves of smell. Or you might sample an article of food, such as an apple. In this case you employ the special nerves of taste, whose endings are located on the tongue.

We have, then, five senses, which are sight, hearing, taste, smell, and touch. We rely upon these senses to make us aware of what is going on about us — to make us aware of changes in our environments. Obviously, our methods of receiving stimuli and our responses to those stimuli are more complex than in the case of plants or simple animals.

The sense organs, such as the eyes or ears, are special parts of a complex nervous system. Their function is to receive certain stimuli, and to make us aware of these stimuli. We note, of course, that not all animals have such special sense organs. Basically, the unit of every sense organ is the nerve cell. We have studied the nerve cell (see pages 293–294) and have learned that its special function is to carry nerve impulses.

Problems of stimulus conduction. When an animal's body consists of many cells, some of them are likely to be far removed from the point at which a stimulus is received. It is necessary that these cells be "made aware" of the stimulus in order that a uniform response of the body may result. For example, if one side of Hydra touches an object, and the cells on this side of Hydra respond by contracting, the cells on the other side of the body must be "made aware" of the stimulus. If not, there can be no harmony in the contraction of the body as a whole. The transmission of stimuli from cell to cell is what we have called stimulus conduction. We have learned that in Hydra (page 133) some primitive nerve cells are developed. These cells are specialized for the function of stimulus conduction.

Beginnings of nervous system. In Planaria we find the conducting cells concentrated into structures called nerves, and masses of nerve cells are known as ganglia. The ganglia, the nerves, and the specialized cells on the surface, such as those involved in the eye spots, make up a simple nervous system. In

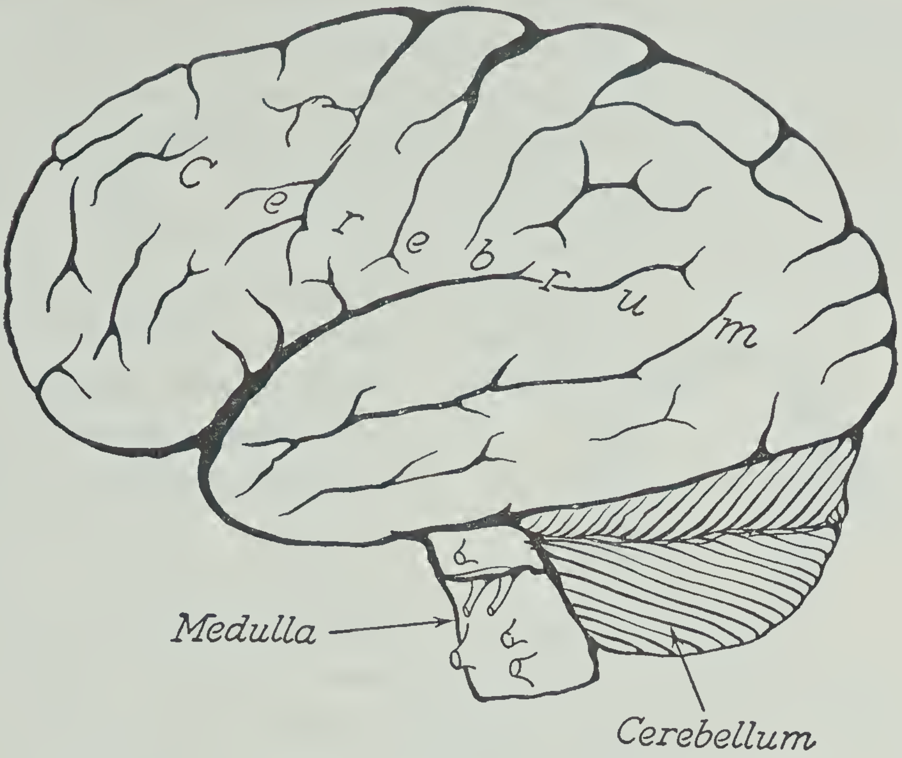

FIGURE 139. Diagram of human brain, side view.

an earthworm, ganglia and branch nerves are found. Insects develop nervous systems with special structures such as compound eyes, simple eyes, and antennae.

Complex nervous systems. Among chordates, the nerve cord is hollow and dorsal in position. Higher chordates develop brains at the anterior end of the nerve cord. The human brain represents the most efficient development of this structure. An examination of Figure 139 shows that it is divided into a cerebrum, a cerebellum, and a medulla. The higher thought processes, such as memory, are known to center in the cerebrum. Functions of the cerebellum and medulla have to do with automatic and reflex acts. Many external stimuli come to the human nervous system by way of the sense organs. Among the special sense organs are the eyes.

The human eye. On the outside, except at the front of the eye, is the sclerotic layer. This layer is seen from the exterior as the "white of the eye." On the front of the eye is the transparent cornea, which is continuous with the sclerotic layer (see Fig. 140).

The cornea and sclerotic layer, taken together, make up the outer covering of the eye. Beneath the sclerotic layer is the choroid. This layer contains numerous pigment (color) spots and blood vessels. The iris is a pigment-bearing membrane, lying behind the cornea. It has a central opening — the pupil — through which light enters the eye. The iris is the colored portion of the eye, as seen from the exterior. The lens lies behind the iris, and is kept in place by fibrous processes which connect with the wall of the eyeball. Liquids fill the cavities in front of and behind the lens. The pressure of these liquids also serves to keep the lens in place. The optic nerve, connected with the brain, enters the eyeball from the rear. It is continuous with the retina. The latter is a layer, containing sensitive structures, which is spread out over the inner surface of the eyeball.

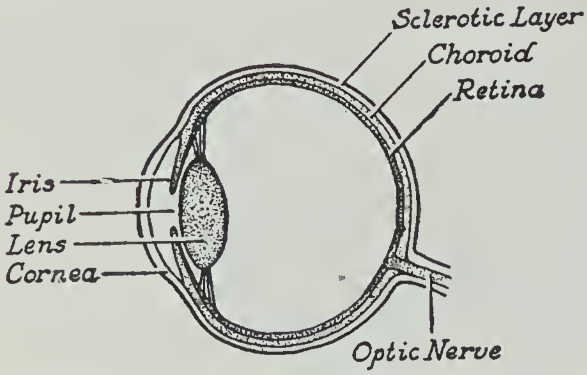

FIGURE 140. Diagram showing some structures of the human eye. Which part of the eye connects directly with the optic nerve?

Expansion and contraction of the iris regulates the amount of light admitted to the eye. The lens is a focusing structure. It changes its shape as a result of muscular contraction. The image is focused upon the retina, which in turn is connected with the brain by the optic nerve.

The human ear. The human ear is another special sense organ. It includes three general regions: the outer ear, the middle ear, and the inner ear. The eardrum (tympanic membrane) is stretched across the entrance of the middle ear. It is set in vibration by sound waves. Three small bones (hammer, anvil, and stirrup) convey the vibrations to the inner ear. The inner ear includes the cochlea and the semicircular canals. Nerve fibers connect these structures with the brain. The semicircular canals seem to function in maintaining balance. The cochlea contains the nerve endings which are sensitive to sound waves.

The human nervous system. Man has the best nervous mechanism for effecting *controlled responses* to stimuli. The human nervous system may be divided into two general parts. These are the central nervous system, and the autonomic nervous system. The ductless glands and their hormones also produce some responses. The central system includes the brain, the spinal cord, and certain nerves which connect directly with the brain. The autonomic system includes the so-called sympathetic nerves and groups of nerve cells. It is connected with the central nervous system, and with the various internal organs. The autonomic system regulates many unconscious acts. Many unconscious acts are also regulated by the central system, but in addition, the central system is also concerned with conscious behavior.

The human brain. The human brain has three main regions. These are the cerebrum, the cerebellum, and the medulla. The brain is made up of centers (synapses) where nerve fibers meet. The cerebrum includes the centers for delayed responses — for thinking and conscious behavior. The human cerebrum is superior to that of any other organism. Such dominance as man has achieved is largely due to the superiority of his mental processes. The cerebellum controls the interplay of muscles throughout the body. The medulla connects the spinal cord with the rest of the brain. It affects various automatic acts, such as breathing, and the action of the heart.

Stimulus-response and the use of energy. Responses to stimuli are sometimes called adaptations. Various stimuli influence the growth of roots and other structures. We adapt our behavior in response to stimuli. Before we continue our study of behavior let us see how energy is related to the stimulus-response concept.

One law of physics holds that every motion or change of motion is proportional to the impressed force. Let us see if this is true of responses to stimuli. A turkey vulture soaring far up in the sky apparently observes the death of an animal, and soon arrives at the spot, awaiting a chance to feast upon the body. Other vultures come from still greater distances. Perhaps they have not seen the death of the animal but have observed that the first vulture dropped down to the ground. The use of energy in flight is far greater than the energy used in observing what has occurred. A common crow discovers an owl sitting quietly upon a limb in the forest. The crow emits cries; then other crows come from all directions — some of them from a considerable distance. They circle about the owl and may spend hours annoying the unfortunate bird, unless the latter is able to elude the crows in the forest, or take refuge in a hollow tree. In the same way, an odor of broiling beefsteak may stimulate you or me to drop our work and go in search of food. In such cases it appears that a stimulus sets up a train of events inside the organism, which releases energy far greater than would be expected in a *simple* cause and effect relationship.

MANY RESPONSES ARE REFLEX ACTS

Reflex action. In the preceding discussion (see page 294) we have studied the structure known as the reflex arc. Through the action of the reflex arc the central nervous system exercises a control of certain muscles. In a simple reflex, a stimulus is carried to a nerve center, such as the spinal cord. Then another impulse is conveyed to the muscles, which perform the response.

Like tropisms, reflexes are responses to stimuli. Some reflexes are of a simple nature, and, as a group, they are involuntary acts. Much of the behavior of animals which develop nervous systems [1] represents reflex action. Some reflexes are hard to distinguish from another group of acts which are said to represent "instincts."

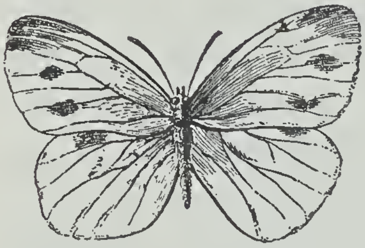

FIGURE 141. A cabbage butterfly.

Instincts. Let us examine some examples of instinctive behavior. When a cabbage butterfly emerges from its pupal stage, it may never have seen a cabbage, or an egg, or another butterfly. It does, however, mate with another butterfly of its own species. The female lays her eggs on cabbage leaves, and the eggs hatch to produce larvæ — the familiar "cabbage worms." The larvæ eat, grow, and eventually spin the cocoons in which the pupal stage is passed. Many of the acts performed during the life cycle, such as laying eggs on cabbage leaves, eating cabbage leaves, and spinning cocoons, are *unlearned* acts. The organism could have no previous experience with such matters. We sometimes call such behavior "instinctive."

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[1] According to one definition, organisms which do not possess nervous systems also may perform reflex acts.

Similarly, we say that the flight of newly developed moths toward a bright light is instinctive, because it seems to be an example of *unlearned behavior* and because it is a *typical response.* We may say, then, that typical behavior of an organism, which appears in response to a new stimulus, is the result of instinct. Probably the instinct depends upon the presence in the body of an inherited, ready-to-act arrangement of nerve cells and muscle fibers (reflex arcs). It is said that reflexes are the most complex responses that are made without any previous learning.

SOME REFLEXES MAY BE CONDITIONED

Many experiments with animals of various orders and phyla have convinced scientists that much of the behavior of animals ranked below the vertebrates is of a reflex nature throughout their lives. Thorndike, Pavlov, Jennings, Watson, Kohler, and others, have contributed many valuable studies to add to our knowledge of the "conditioning" of reflexes, and of the instinctive behavior of animals. A few of these experiments will illustrate the kind of work that is being done.

Some of Pavlov's experiments. Professor Pavlov, a Russian, experimented with the conditioning of a dog's behavior toward food. He had observed the well-known fact that saliva flows in a dog's mouth when food is tasted. He noted that after acquaintance with a certain kind of food, the mere sight or smell of this food resulted in responses by the dog, such as lip-licking and mouth-watering. This suggested memory of the previous experience.

Just how these responses worked was the question Pavlov wanted to answer. He therefore proceeded to get more facts. A dog was placed in a quiet room. Presently the clicking of a metronome, a sound unfamiliar to the dog, was allowed to be heard. A few seconds later a plate of food was placed in the room. The dog smelled, and examined, and then ate. When the meal was over, the plate was drawn away. After a few hours, the clicking was started again, and another plate of food appeared, which was feasted upon. Thus for several days, each appearance of food was preceded by the sound of the metronome. Soon it was observed, through a suitable peephole, that the dog's actions changed. At first it paid no attention to the clicking. After a few experiences, however, it began to exhibit licking of the lips and a flow of saliva whenever the clicking sound began.

This behavior of the dog is explained as follows: at first the dog had an instinctive response to the stimulus of food; namely, flow of saliva. But the dog learned that the clicking preceded the approach of food. Hence there was built up a reflex which associated the clicking sounds with the appearance of food. Since there is no natural connection between the sound of a metronome and a dog's salivary glands, the response was said to have been "conditioned." Later Pavlov succeeded in bringing about a response of saliva flow, etc., to the stimulus of an electric shock and to the sound of dinner bells.

Actions of cats and dogs. Our own everyday experiences will probably furnish us with many other examples, if we try to recall them. For instance, if we study the behavior of a dog and a cat we may see evidences of the same sort of mechanism. A cat's appearance to a young dog may set up the response "to chase." The appearance of a dog to a cat may result in "bristling hair," "bushy tail," "humped back," and other familiar responses. These doubtless are reflex acts. Yet this behavior can be changed. If the dog's master punishes the dog, or speaks sharply to it each time it chases a cat, the dog may learn to meet the stimulus of seeing a cat without attempting to bark or give chase.

Hence we see that dogs can have reflex acts modified by certain experiences. This modified behavior, based upon an original instinct or reflex, is called a conditioned reflex. The process of bringing about a different stimulus-response is called "conditioning."

INTELLIGENCE

(Involves memory, and the ability to delay response)

Memory. We have noted that the dog can be "conditioned." Its response to a stimulus for which it has a reflex arc can be overcome by repeated punishment. Eventually, the appearance of a cat as a stimulus is always associated with the punishment. This implies memory. Memory represents a learned response which is retained by the nervous system.

The punishment naturally caused pain. This pain was a response of some nerves other than those affected by the sight of the cat. But the "pained" nerves were related to the "cat-responding" nerves. The muscles which make the dog's legs move were directed by one stimulus — the memory of pain — to remain still. We say this "cat-pain-be-still" impulse was stronger because it involved more of the dog's bodily well-being than did the "cat-run" impulse. It also was stronger because it overcame the other action.

This explanation may assist you to understand the conflict of impulses that arises in a nerve center when various nerve fibers bring in "messages." If one of the "messages" is associated with a "run" response and the other with a "stand still" response, a problem results. Action is delayed by some means not yet fully understood. The delay occurs in the center or centers to which the "message" comes. This delay of the response is the second aspect of conditioned behavior.

Factors in intelligence. The beginnings of intelligent behavior are seen, then, in (1) memory, or the ability to recall past experiences, and (2) the ability to delay response in a higher center where many nerve cells are grouped together. A third factor, the possession of long-distance receptors such as eyes, ears, and the sense of smell, is no doubt important but not essential. Insects have distance receptors, but are not ordinarily considered to be intelligent. Some people are deaf and blind, but nevertheless intelligent.

Low intelligence is correlated with poor ability to remember, and with little ability to delay a response to a stimulus. Higher intelligence appears to be accompanied by better memory, and ability to delay responses. It will be seen at once that the possession of a great number of instincts, or the possession of strong instincts, tends to prevent intelligent behavior.

Can intelligence be defined? Intelligence, then, is not a thing or faculty. It could perhaps be defined, but we shall not attempt to do this. You may now understand, if you have followed the preceding discussion, that intelligence is a single word that describes *some* behavior of *some* higher animals. It is behavior in which response is delayed within the organism, while previous experiences are associated with the present situation.

It is not uncommon to hear lovers of household pets remark: "What a smart dog!" Or, "My cat understands everything that I say to him." Certainly some cats and dogs do show in their acts that they modify their behavior in the light of past experiences. Since these animals show by their actions that they profit by past experiences, they may be credited with a certain amount of intelligence.

As we study animal life we observe that according to this idea of intelligence, some animals are more intelligent than are others. Bears, dogs, mice, birds, horses, seals, lions, and elephants can be taught to do "tricks." They can learn some things by "conditioning" or "training." Other animals appear to be unable to learn ways of doing things other than those which are instinctive. A spider builds the same kind of web as did its parent, although it did not have to learn the process. Beavers do not have to take courses in engineering in order to build a dam. But beavers do not build exactly the same kind of dam on every occasion. Situations vary. Problems arise for which no ready-made response has been provided. Some animals appear to be able to learn, or to profit by experience.

Learning in animals. Experiments by Thorndike have shown that fish can learn to find openings in a glass partition, after repeated experiences of searching for them, by failure and success. Kohler has experimented with apes and has found that they (some better than others) can make use of experiences to guide them in other situations.

For example, apes were given the problem of getting bananas from the top of a cage far out of their reach. Boxes were put in the cage. After repeated trials one of the apes found that the boxes could be piled up so as to furnish a means of reaching the fruit. Thereafter, when bananas were put in the top of the cage, this ape very promptly used the boxes to get at them.

No great skill was used in piling the boxes, nor was there any apparent understanding of center of gravity, or size of box. However, the fact is that the response to the situation was learned. Memory appears to have been involved, and action seems to have been directed by some sort of association with previous experiences.

Human intelligence. At birth, the human infant is one of the most helpless of all animals. A baby cannot walk, or talk, or succeed in any of the activities of maintaining life, unless someone provides the necessary care. A child needs care and protection for several years before it is able to obtain its own living. In contrast, a chick newly hatched begins to walk and pecks at objects on the ground almost at once. If chicks are hatched in an incubator, and supplied with water and food, they may carry on life activities and grow to maturity without any parental care.

The capacity for mental development in the human child, however, is far greater than that of the chick or any other animal. If a chicken lives to be four years old, it will be larger, but it will have very few abilities which it did not have at the time of hatching. On the other hand, a child four years old can walk, and talk, build houses from blocks, eat with a spoon and fork, and respond "intelligently" to a great many situations. The child inherits the *capacity* to become an intelligent organism. It is through experience and education that this capacity is *developed.*

From the standpoint of intelligence, man is far superior to all other organisms. We apparently possess a nervous system whose structures are very sensitive to stimuli of many kinds. The conducting nerve cells are capable of speedy transmission of impulses. We have centers where thousands of nerve processes meet in various parts of the body. The brain and the spinal cord are notably large centers of this sort. Moreover, we are able to retain responses as memories. Finally, the groups of nerve-cell bodies in the nerve centers, have a wonderful capacity for delayed response.

Human instincts. If our principles are correctly derived, we should find that man possesses few instincts. The facts support this theory. A human infant has, perhaps, the fewest instincts of any animal. Sucking, grasping, random motions — these are about all, and they could be classified as types of reflexes. The life functions, respiration, circulation, digestion, and excretion tend to take care of themselves — they are automatic acts. The human child requires a long period of care because it is learning to carry on life in an environment to which it has few instinctive responses.

What is learning? In man, learning appears to be the building up in the nervous system of a large number of responses to stimuli. These responses are those that have proved to be satisfactory in the past. They are "stored" as memories in some way not fully understood, and when situations arise in which the stimuli which caused them are again present, the responses are ready.

Thus a child is given candy. It stimulates the taste buds. It gives a sweet, pleasant sensation. Each time a small piece of this candy is put in the child's mouth, the response is satisfying. Soon the child has *learned* to respond to candy by putting it in its mouth. The original response may have been due to the instinct to take food, or to move the hands, or to both. The learning process has affected, in some way, the nervous tissue, or the association of nerve cells. The child also might learn to avoid candy, or to eat spinach, by proper conditioning of its behavior.

Habits. Animals which possess nervous systems capable of memory and delayed response can learn by conditioning the response. An act repeated many times with satisfying results may become a fixed response to a given stimulus. A learned reaction to a stimulus, which has become so definite that a higher center does not delay the response, is called a habit.

How we think. Every normal human being can think and does think. We do not have to be taught to think. However, it is apparent that some persons think more effectively than do others, and that improvement in thinking can be made. Going to school is supposed to give training in thinking.

Thinking takes place between the time when a stimulus is received and the time when a response is made. If we were some other type of animal, the stimulus might bring only one response — the unlearned, reflex-arc response. But in the case of man, the response may be delayed, while the brain center associates the situation with previous experiences. Thinking demands that we *wait* until previous experiences can be related to the present problem.

Handicaps in thinking. Two handicaps may interfere with thought and prevent many people from becoming good thinkers. First, the lack of experiences. No thinking can occur unless previous learning has built up a store of responses which can be related to a problem at hand. One cannot decide what is the best way to do a task unless he knows more than one way of doing it. A child who has had experience only with a bottle or its fingers in eating, cannot do any thinking about whether to use a fork or a spoon or a knife, when first placed at the table to eat. Second, habits tend to eliminate thinking. After a child has been permitted to eat with its fingers for many months, the response to the stimulus of food is established as a "food-fingers-mouth bond." The behavior has become fixed as a habit.

Are habits useful? Some habits are useful because they save time. The higher centers do not have to postpone action in situations for which habits have been formed. The reflex arc takes care of the action. On the other hand, it is plain that to act in another way than the habit way, requires that the habit be broken. Breaking habits is not easy in all cases. We need to be careful, in forming habits, that we acquire those which are desirable. Many routine matters of our lives can be taken care of by habit responses. Some rules for the formation of habits have been made by psychologists. Perhaps you can help yourself to form a desired habit by studying them.

Some rules for habit formation:

1. Convince yourself that the habit is of great importance to you. Get enthusiastic.
2. Start in strong with determination to form the habit.
3. Perform the act carefully the first few times, with no mistakes.
4. Practice by repeating the act at every opportunity. Make opportunities.
5. In training, do not practice mistakes.
6. Make no exceptions. Do not allow a single departure from the habit.
7. Think about what you are trying to do as a reflex act that you are trying to fix in your nerves and muscles.

Studying. The principles of learning ought to be useful to you. They will be, if you understand that *these principles apply* to everything you do. If learning consists in relating new experiences to old experiences, you should try to recall all the old experiences you can, when you are studying a new topic. Do not try to learn statements word for word, but try to understand the *meaning* of the statements.

"Meaning" is just another way of saying, "relate the statements to previous experiences." When you study Paramecium you must recall Amœba. To understand conduction of liquids in plants, you must recall life functions of protoplasm, cell colonies, the microscopic appearance of a leaf, the cross section of a stem, ink rising in xylem, root hairs, leaves making food in the sunlight, roots far from the leaves, leaves not in contact with water, and numerous other experiences obtained by reading, by observation, or by experiment. If you will regard studying as a *process of building* within yourself a multitude of related experiences and a body of principles about how things work, you will be successful.

Biology is a study of the principles of life. Learning these principles is a process of getting experiences and of relating them, so that they can be seen as of very general application. If tomorrow you look through a microscope at the blood vessels of a frog's foot, it will be an experience. However, unless you think about it by recalling life functions, nutrition, circulation, respiration, oxidation, blood from a cut finger, and perhaps many other experiences previously met, this experience is likely to have little meaning.

Intelligent behavior. Intelligence presumes the existence in us of a well-developed nervous system. Intelligent behavior results from conscious use of this structure. You may have the capacity for intelligent behavior, but not behave intelligently. You can make better use of your intelligence if you try to make use of your experiences in all that you do. Form good habits of work and thought. Decide matters after thought. Get facts. Relate the facts together. Do not depend upon the opinions of others, but upon your own related experiences which represent facts. These are some of the rules involved in the principles of intelligent behavior.

Summary. In conclusion, we have learned that many responses are more complex than the simple responses that are called tropisms. Many animals develop nervous systems which include reflex-arc structures, and in some cases special sense organs, spinal cords, and brains. The human nervous system represents the highest type of development, and man has the greatest capacity for intelligent behavior.

Some responses may result in adaptations of behavior, and even adaptations of structure. The energy used in making a given response may be vastly different from the energy involved in producing the stimulus. Among animals, many responses are of the reflex type; others are classified as instincts. Reflexes and instincts do not involve learning, but some reflexes may be conditioned.

Intelligence involves memory and the ability to defer response to a stimulus until the problem has been associated with past experiences. A number of higher animals show certain abilities to learn, but the human capacity for mental development is far greater than that of any other animal. Habits are responses, which through repetition have become fixed. Fixed habits tend to eliminate thinking, which may be undesirable if the habits are not good habits. Thinking also may be handicapped by lack of suitable experiences. In studying, it is desirable to relate the material at hand to previous experiences.

SUGGESTED ACTIVITIES

Scientific methods

A scientist makes collections of specimens or samples for a definite purpose.

1. Study one or more domestic or laboratory animals for a period of weeks, and report evidences of behavior which you believe: (*a*) to be instinctive, (*b*) to be learned, (*c*) to give evidence of "thinking."
2. Secure copies of some "intelligence test." Administer the test and calculate the "intelligence quotient" by use of the directions given. Discuss to what extent previous experience is involved in ability to make the correct responses.
3. Obtain the eggs of some species of moth and allow them to hatch in the laboratory. Appropriate food must be provided for the larvæ. Make observations of behavior throughout the life cycle with special reference to instinctive behavior. Prepare a report.
4. Place a living earthworm upon some surface that is not polished (such as a large piece of blotting paper). Observe its movements in locomotion. Stimulate various regions of the earthworm's body and observe the nature of any responses. From your observations and from previous knowledge concerning this animal's nervous system, how would you classify these responses?

SUMMARY OF PRINCIPLES

1. Many responses are more complex than the simple responses known as tropisms.
2. Many animals develop nervous systems; the human nervous system represents the highest type of development for producing *controlled responses.*
3. Some adaptations of structure, and many adaptations of behavior, are the result of responses.
4. The energy involved in making a response may be much greater than the energy involved in the stimulus.
5. Many responses of animals having nervous systems are reflex acts.
6. Many animals exhibit behavior which is called "instinctive."
7. Reflexes may be "conditioned" in some cases.
8. Memory, and the ability to delay response to a stimulus, are factors in intelligence.

9. A number of higher animals, such as cats and dogs, exhibit ability to profit by experience.
10. The capacity for mental development is greater in the case of the human child than in the case of any other animal.
11. Man has few instincts; much of his behavior is modified in the light of previous experiences.
12. Habits are learned responses to stimuli that have become "fixed" by repetition.
13. The ability to think is inborn, but improvement in thinking can be made.
14. Learning consists of relating new and old experiences; studying should be a conscious application of this principle.

GUIDE QUESTIONS

1. What evidences of (*a*) structure, and (*b*) behavior, indicate that the human nervous system is a highly complex structure?
2. To what extent may responses be involved in adaptations of structure and behavior?
3. Give an example which indicates that stimulus-response is not a simple cause-and-effect relationship.
4. Give an example of a reflex act. Discuss to what extent the responses of higher animals are reflex acts.
5. Which has the more instincts, a man or a dog?
6. What is meant by a "conditioned reflex"?
7. Upon what factors does intelligence depend?
8. Is man the only organism that shows ability to modify behavior in the light of experience?
9. Are habits desirable or undesirable? Explain, and give examples.
10. How is "learning" accomplished? How may this knowledge be applied in developing good habits of study?

BOOKS TO READ

Dorsey, G. A. *Why We Behave like Human Beings.*
Hingston, R. W. C. *Instinct and Intelligence.*
Jennings, H. S. *The Biological Basis of Human Nature.*
Wiggam, A. E. *Exploring Your Mind with the Psychologists.*
Woodworth, R. S. *Psychology.*

CHAPTER XXI

SPECIAL ADAPTATIONS

Problem:

What are some special adaptations of structure and behavior that are exhibited by organisms?

Foreword. Most of the responses considered in Chapters XIX and XX represent adaptations of behavior. Some of them involved adaptations of structure. In previous discussions we have considered numerous adaptations of plants. Many of these had to do with life in different habitats. Others were concerned in the food-making process. In a future discussion we shall consider plant adaptations related to the dispersal of pollen and seeds. In this chapter we shall be concerned mainly with special cases of adaptation among animals. We should remember that all organisms exhibit adaptations, but only a limited number of cases can be discussed here.

THERE ARE MANY ADAPTATIONS FOR LIFE IN DIFFERENT HABITATS

Adaptations for arboreal life. Some adaptations are associated with arboreal life. Tree frogs, for instance, have suckerlike pads on their feet. These pads aid them in clinging to vertical surfaces. Certain species of monkeys have prehensile tails; that is, tails that can be used in grasping. Such use of the tail as a grasping structure also is exhibited by the Virginia opossum. The sloths of South and Central America furnish another example of arboreal animals. In the case of this type the curved claws turn inward and the animal clings to a branch while hanging beneath.

Adaptations for flight. Among the structures which fit animals for aerial habits we find the wings of birds, bats, and insects. These three types differ from one another. The wing of a bird depends upon the development of feathers which are part of the external skeleton. The bat wing represents a membrane which extends between the fore limbs and the hind limbs and even connects with the tail. The wings of insects are totally different types of structures. As we have learned, some insects have two wings and others have four wings. In either case, the wings represent extensions of the external skeleton, and the veins of the wings are developed from the respiratory tubes known as tracheæ.

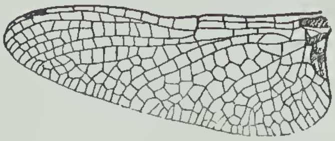

FIGURE 142. The wing of an insect. Do you suppose that the veining of the wings of insects of the same species is alike? How would you determine whether or not your guess is correct?

Some other animals are able to glide through the air but could scarcely be called aerial. This group includes the so-called flying fishes and the flying squirrels. In the former case certain fins are enlarged to form the gliding structures. The fish may leap into the air and sail above the surface of the water for some distance. In flying squirrels, lateral folds of the skin enable the animals to glide from higher to lower elevations.

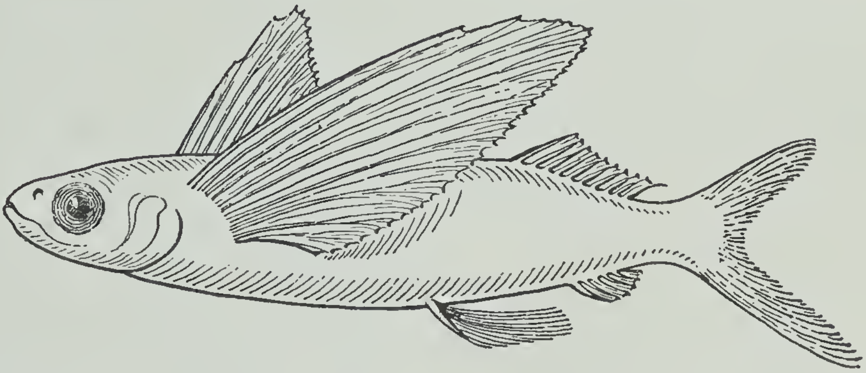

FIGURE 143. A flying fish. Does this fish really "fly"?

Adaptations for subterranean life. We have learned that earthworms eat their way through the soil. They do not develop such sense organs as eyes. Some other worms that live in water where they come in contact with light develop simple eyes. The mole and the pocket gopher are other well-known subterranean animals. Both types are marked by the development of the fore limbs as digging structures. The pocket gopher has two cheek pouches in which various materials, even food, may be carried. The eyes of the pocket gopher are small; in the mole they are even smaller — in fact, rudimentary.[1]

Adaptations for aquatic life. Many adaptations for aquatic life have to do with the animal's oxygen supply. Among the more obvious of the structures are the gills of fishes. Some aquatic insects come to the surface to obtain air. Certain other species have tracheal gills which are gills associated with the spiracles (see page 144). A few aquatic insects carry bubbles of air down into the water beneath their bodies. These bubbles of air are kept in contact with their spiracles.

A whale represents a mammal that is adapted for life in the water. It has a layer of fat beneath the skin that gives protection against adverse temperatures. The fore limbs are suited to use in the water. Whales have no external ears.

Among semiaquatic organisms we find such structures as the webbed hind foot of a frog, which is of aid to the animal in swimming. The feet of ducks and geese likewise are webbed. So are the feet of some other birds that are associated with water habitats. The Mexican jaçana is an unusual type of bird in that its toes and claws are greatly elongated. This fact enables it to walk about upon lily pads at the surface of the water.

Adaptations for terrestrial life. Among terrestrial animals we find adaptations of many kinds. The horse has a hoof which represents one toe of the foot. This type of foot is suited to running over hard, dry soil. The padlike feet of the elephant are more nearly suited to supporting a heavy body on the softer soil of jungle trails. The camels possess a number of adaptations suiting them for desert life. Their padlike feet are adapted to walking on sandy soil. Cells lining their stomachs absorb a reserve supply of water, which enables the animals to go without drinking for a considerable time. They also have reserve supplies of food in the form of fat, which is stored in the humps.

ADAPTATIONS MAY BE CONCERNED WITH OBTAINING FOOD

Adaptations for obtaining food. Adaptations concerned with obtaining food are extremely common among animal species.

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[1] Undeveloped, and do not perform a normal function of eyes.

Only a few cases can be mentioned here. We have learned how Hydra uses its nematocyst cells and tentacles to capture small organisms and convey them to its mouth opening.

A starfish. Another interesting case is presented by the starfish Asterias. This animal develops what is known as a water-vascular system. One feature of this system is the presence of many tube feet having suckerlike tips, on the under surface of the body. These tube feet, through co-operation with other parts of the water-vascular system and the muscles, are used in locomotion. They also are employed in pulling open the shells of oysters and other bivalves.

A starfish has a relatively large, circular, mouth opening, and a pouchlike stomach. When the shell of the bivalve (the prey) has been opened, the stomach of the starfish is everted or pushed out of the mouth opening and carries on the digestion of the soft parts of the victim. When this process has continued to a certain stage, the stomach, together with its digested and partially digested contents, is drawn back into the body of the starfish.

Bloodsucking animals. The vampire bats of South America obtain food in the form of blood. To do this they must make cuts in the skins of their victims. It is even claimed that they will attack sleeping human beings. Leeches, discussed elsewhere, also are bloodsuckers. So are some insects, including certain mosquitoes and flies. The latter develop sucking (suctorial) mouth parts, armed with piercing structures in the form of bristles, with which the skins of animals are punctured.

Anteaters. Another type of South American animal that is adapted to obtain a particular kind of food in a definite way is the anteater. This animal has its facial region prolonged into a tubelike proboscis, with the mouth at its anterior end. The snout is thrust into an ant burrow, and then the long, slender tongue, which is covered with a sticky secretion, is thrust among the ants. The ants adhere to the tongue and are thus carried back into the anteater's mouth.

Deep-sea fishes. Certain deep-sea fishes develop luminous[1] bulbs which extend forward and above their mouths on short stalks. Apparently these structures lure other, smaller organisms, which serve as food, within easy striking distance.

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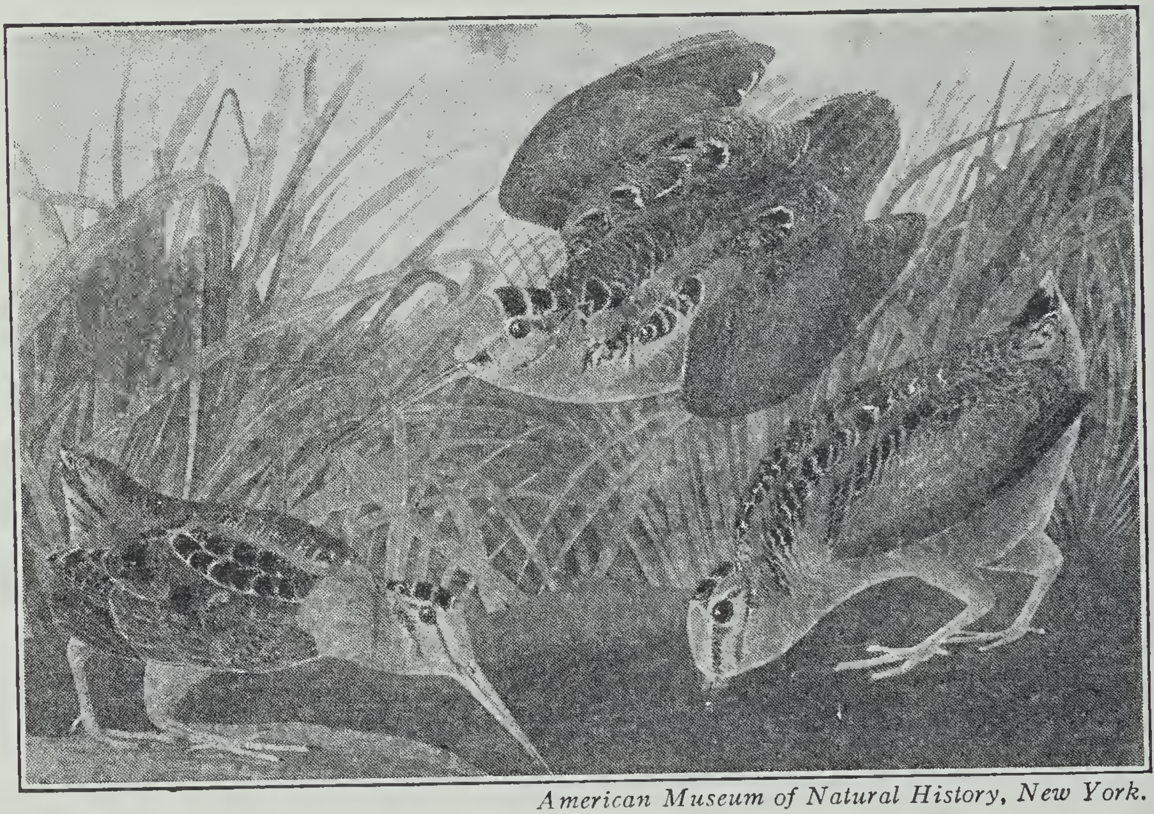
[1] Give off light.

Teeth. The incisor teeth of many rodents, such as beavers, rats, squirrels, and woodchucks, grow throughout the lives of these animals. Probably this is a fortunate fact, since the wear caused by gnawing wood and other substances would otherwise soon render these teeth of little value. Carnivorous mammals, on the other hand, have relatively large, long, and pointed canine teeth, and the rest of their teeth are suited to tearing flesh. Herbivorous animals tend to have chisel-like teeth in the anterior parts of their mouths, and their molars and premolars usually have flat, grinding surfaces.



American Museum of Natural History, New York.

FIGURE 144. The American Woodcock. Note use of the probing type of bill.

Bills and claws. The bills and claws of hawks and owls represent adaptations for capturing prey. The bills have the upper portion curved downward and sharply pointed. This type of bill is well-suited for striking at a victim, or for tearing flesh.

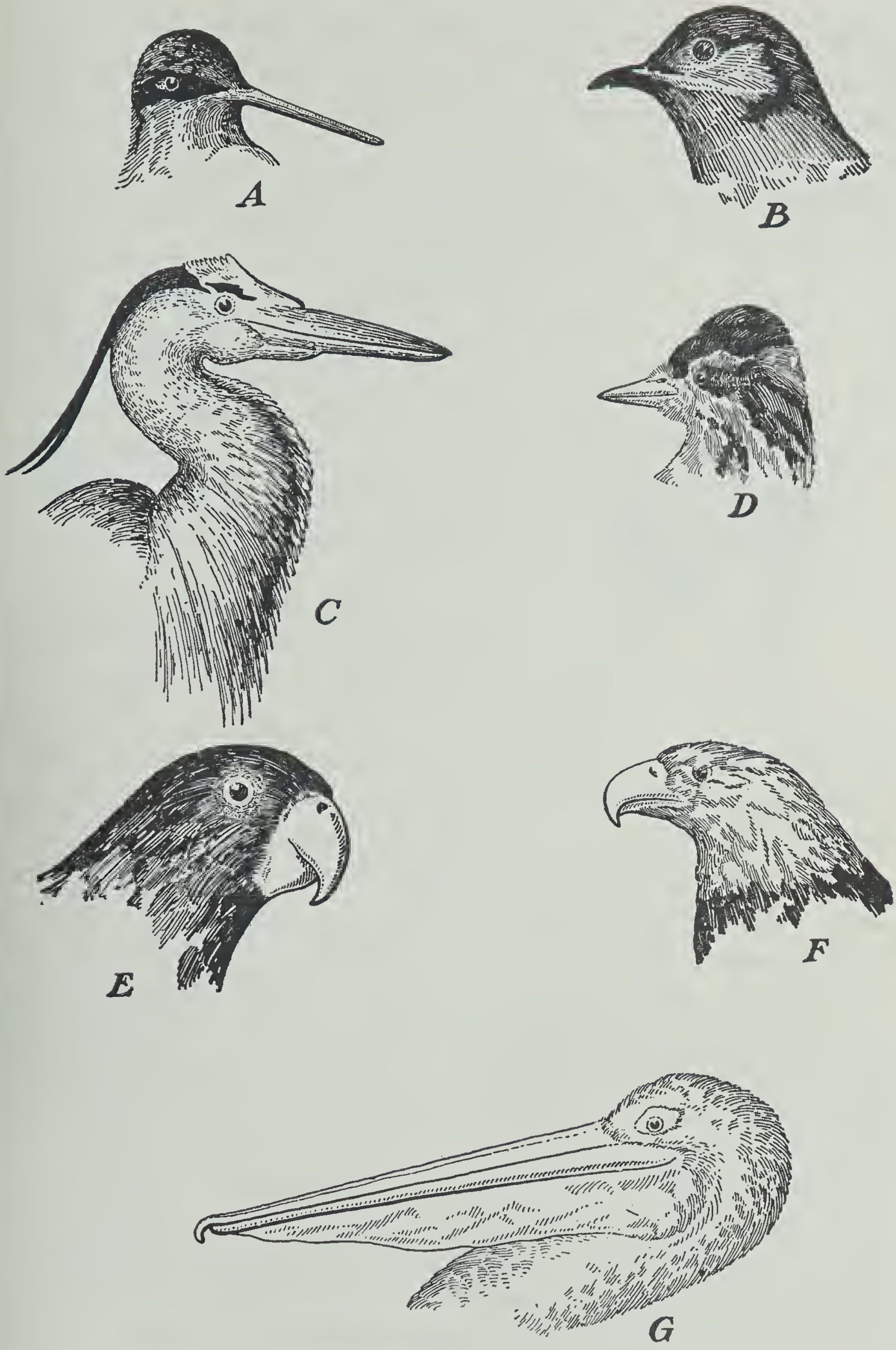


FIGURE 145. Bills of various types of birds. *A*, hummingbird; *B*, bluebird; *C*, heron; *D*, woodpecker; *E*, parrot; *F*, eagle; *G*, pelican. Can you tell for what purpose each type of bill is adapted?

The feet likewise are strong, and are armed with sharp, curved claws, which may be used effectively in grasping the prey. Other bird bills are adapted for a variety of uses in connection with obtaining food.

Ichneumon flies. Certain species of ichneumon flies have interesting habits and adaptations in connection with the fact that their larvæ are parasitic upon other insects. Females of such ichneumon flies have long ovipositors (see page 144) attached to the posterior ends of their abdomens. With the aid of these structures their eggs may be laid *in* the bodies of the larvæ that serve as hosts.

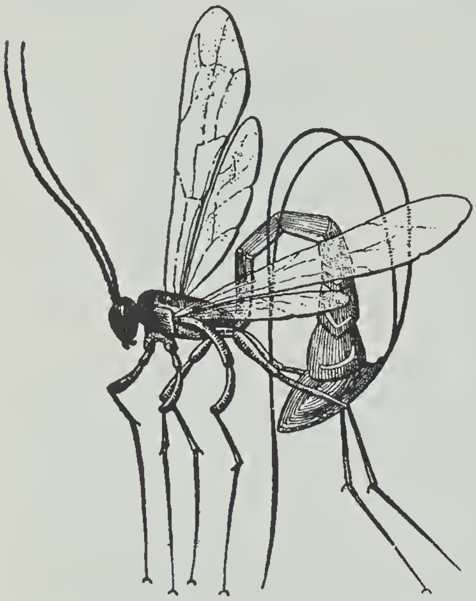


FIGURE 146. An ichneumon fly. Why is this type of insect important to man?

MANY ADAPTATIONS AFFORD PROTECTION AGAINST ENEMIES

Coloration. The coloration of many animals blends more or less with the coloration of their environment and sometimes is referred to as protective coloration. Such coloration is probably of value to the animal in escaping observation by its natural enemies. A number of good examples are found among insects and birds in particular.

The female woodcock, for instance, is a bird that is relatively inconspicuous as she sits upon her nest, placed upon the ground and among dry leaves and grasses. The green coloration of katydids, and of a host of other insects that are found upon grasses, blends with the green coloration of their environments.

Seasonal change in coloration. Some species change coloration with changes in the season. Certain hares which live in northern regions become white during the winter months when the ground is covered with snow. The bird known as the white-tailed ptarmigan has white plumage during the winter, but is brown and gray during the summer. In the spring and fall it presents a mottled appearance. Some weasels and the arctic fox develop white coloration during the colder months, but in these cases the coloration, while it is in a sense protective, may also enable these animals to approach their victims with less chance of being seen.

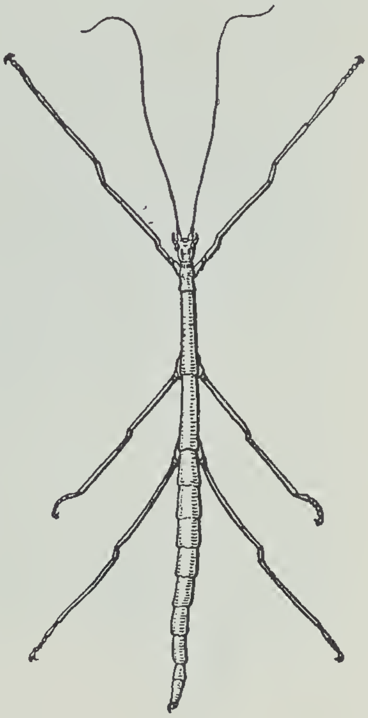


FIGURE 147. A walking-stick insect.

Mimicry. Some animals resemble certain objects or other animals, not only in coloration, but also in form. We have chosen to call such phenomena cases of mimicry.

Walking-stick insects. The walking-stick insects furnish an example of this type. They are colored like the vegetation upon which they are found — even change coloration from greenish in summer to brownish in the autumn. But in addition, their long, tubular bodies, and long, slender legs resemble a mass of twigs when the insects are resting upon branches.

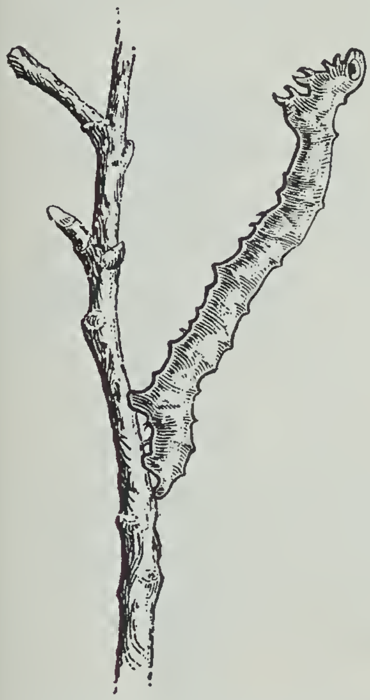


FIGURE 148. A geometrid moth larva.

Geometrid-moth larva. Perhaps an even better example is furnished by the geometrid-moth larva. This larva has more or less the coloration and appearance of a twig. Furthermore, in attaching itself to a branch, it may assume the position of a twig, as shown in the accompanying figure.

Dead-leaf butterfly. Another classic example is that of Kallima, the so-called dead-leaf butterfly, found in the East Indies. The wings of this species are rather brightly colored upon their upper surfaces, but their lower surfaces are similar to dead leaves in appearance. The resemblance is both a matter of coloration and form. Hence, when the insect is in flight, it is fairly easy to see. But when it alights upon a twig, and the wings are folded together so that only their lower surfaces are visible, the insect becomes very much like a dead leaf in appearance.

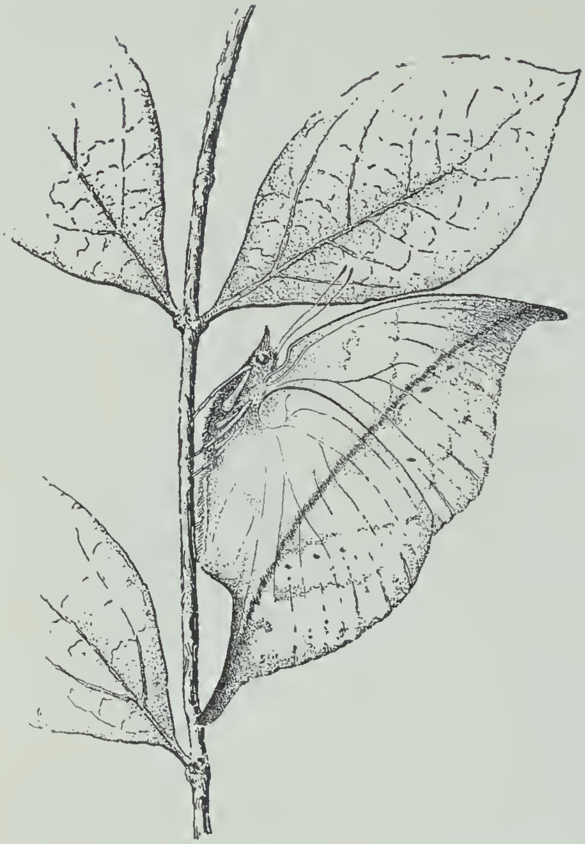


FIGURE 149. Kallima — the dead-leaf butterfly.

Bee flies. Some other animals which possess no special defense structures of their own resemble certain species that do have such structures. Perhaps the former are protected to a varying degree because of this resemblance or mimicry. For example, certain bees having stinging structures are brightly colored. Some species of flies, called bee flies, resemble bees as far as general appearance is concerned. Of course bees have four wings and flies have only two wings. Even humans, however, often avoid bee flies, being misled into thinking that they are bees, and that accordingly they possess stinging structures.

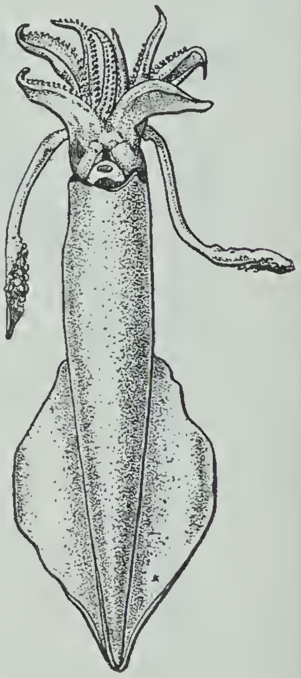


FIGURE 150. A squid.

Squid. The ink sac of a squid may be regarded as a special defense structure. A squid is a marine animal belonging to the mollusk group. It has a saclike structure in which is secreted an inklike fluid. When a squid is threatened by an enemy this fluid is discharged and may serve to discolor the water, while the squid makes its escape.

Scales. Scale insects are tiny bugs which develop protective coverings called scales. Some adult scale insects move about from place to place, but in many species, and especially in the case of females, the adults are fixed[1] in position. In some cases

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[1] Permanently attached to one spot.

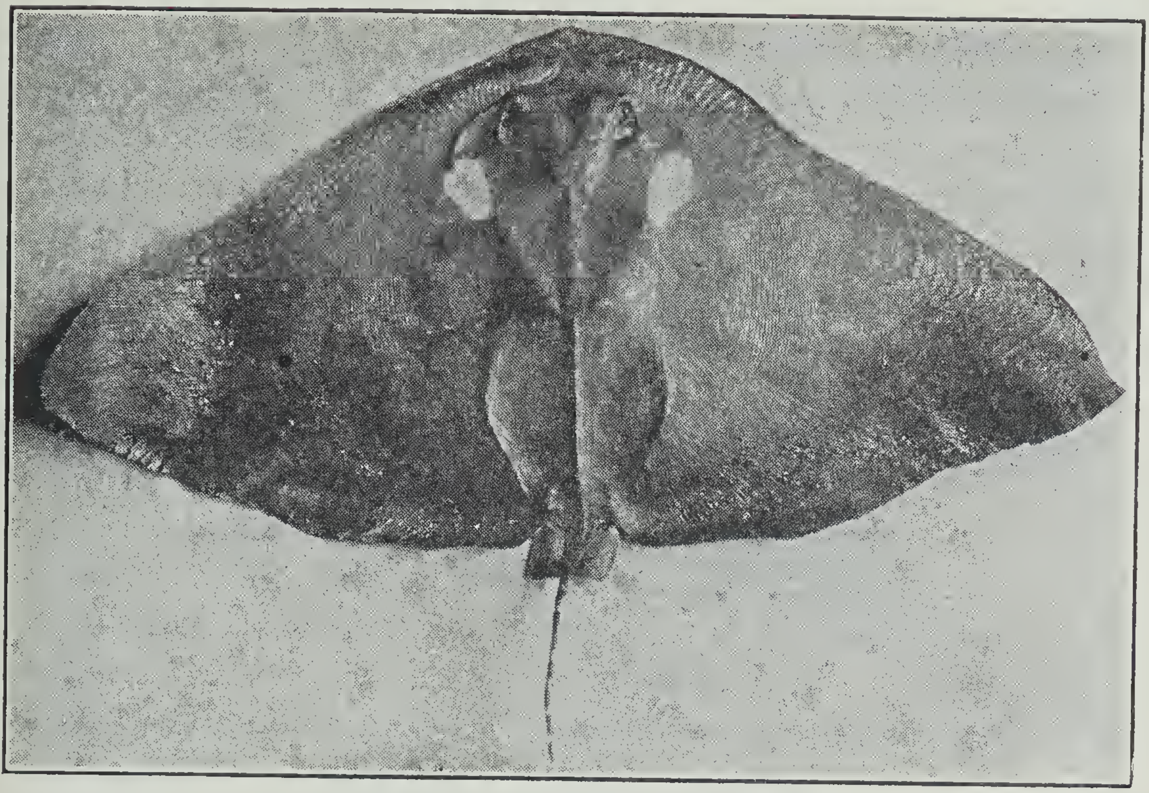


FIGURE 151. A butterfly ray. (Courtesy of Professor H. R. Dill.)

even the eggs are laid under the scale that has been developed by the female.

Sting rays. Stings of various species of bees and wasps have been mentioned before. A less familiar example is found in the case of the sting rays. This type of marine animal has a barbed spine attached to its tail. The spine may be driven into the body of an enemy when the tail is lashed back and forth in the water.

Porcupines. Spines of porcupines are similar defense structures. These spines also have serrated ("saw-toothed") edges. When they have been pushed through the skin of an enemy they remain attached thereto, and often continue to work into the flesh. Porcupines are not able to "throw" their quills at an enemy.

Electric rays. Electric rays are marine animals that have an unusual defense structure. This structure consists of a pair of electric organs which are able to shock an enemy. Similar electric structures are developed by a catfish of the Nile River, and the electric eel of South America.

Hermit crab. The hermit crab, found in salt water, makes use of the empty shells of marine snails as places of retreat. The crab may lie within such a shell with only the anterior end of its body exposed in order that it may obtain food. In some cases a sea anemone, which like Hydra has stinging cells, may be attached to the shell occupied by a hermit crab. It is possible that additional protection is afforded by the presence of the sea anemone.

Other defense structures. Many other examples could be given. Among them might be mentioned the scent glands of skunks, the venom glands of some snakes and lizards, the protective plates of turtles and armadillos, the spines of certain fishes, and poisonous or ill-tasting secretions of the skin that are found in some instances. In many cases, it should be remembered that structures which serve to obtain food, such as the teeth of carnivores, may also function as defense structures.

SOME ADAPTATIONS SERVE TO PROTECT THE YOUNG

We find among animals many special adaptations which serve to protect and insure the survival of the young. These adaptations may be connected with habits, or structure, or both.

Eggs of insects. Insects, as we have learned, usually deposit their eggs where food is likely to be available to the larvæ. In some circumstances, the eggs are deposited in protective cases. This occurs, for example, in the case of grasshoppers. The egg cases of the female grasshopper are deposited in the ground. In a certain species of water bug the male carries the eggs attached to its dorsal surface. Female crayfishes and female lobsters carry their eggs attached to the ventral surfaces of their bodies (abdomens).

Eggs of the skates and whelks. The eggs of skates[1] are deposited in egg cases. So are the eggs of another group of marine animals, the whelks. In the latter case, chains of egg cases are developed, which commonly are called "sea necklaces." Each case contains a number of eggs. The egg cases of skates and whelks often are washed upon our beaches and may be familiar sights to people who live near the sea.

[1] Marine animals belonging to the group which includes the sharks and rays.

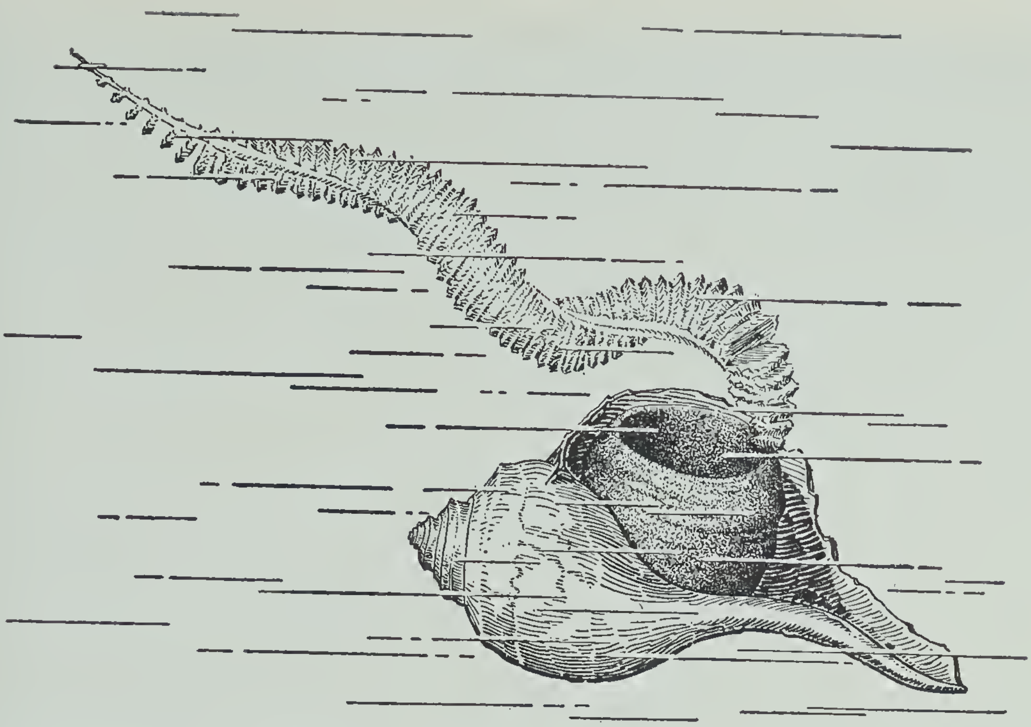


FIGURE 152. A whelk with its egg case. Look for one of these egg cases when you visit a beach.

Marsupial pouch. Of course, the marsupial pouch of kangaroos is a well-known example of this type of adaptation. This pouch is a fold in the skin of the abdomen, which provides shelter for the young for a period of time following birth. The young are relatively immature at birth. The marsupial pouch is developed by other members of the same order of animals, including the Virginia opossum.

SOME ANIMALS EXHIBIT ADAPTATIONS TO PERIODIC CHANGES IN THEIR ENVIRONMENTS

Encystment. Some animals are able to adapt themselves to certain changes in their environments that occur with the changing of the season, or merely occur from time to time. We have already observed that some of the lower organisms, including a number of protozoa, are able to develop cysts about themselves. Within the cysts they survive and may even reproduce during periods that are not favorable to active existence.

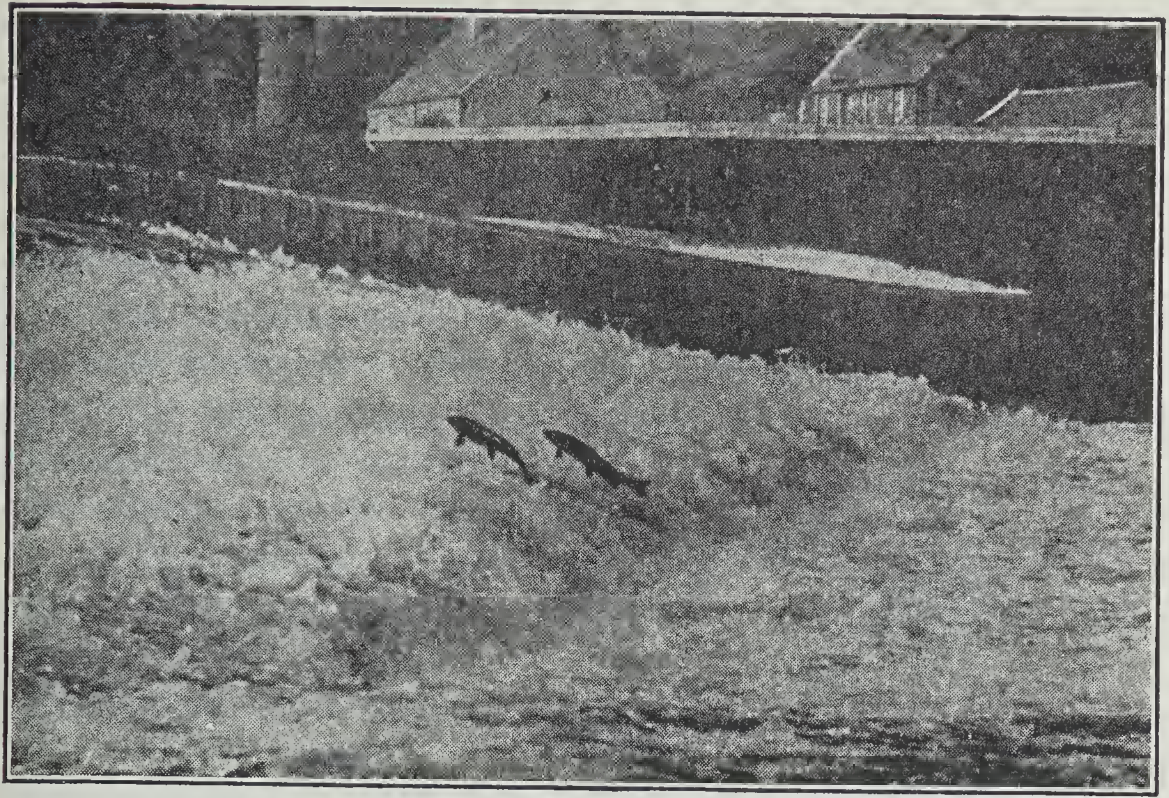
Hibernation. Hibernation represents an interesting adjustment of the animal to periods when the temperature is too low for active existence. In hibernation the rate of metabolism is greatly reduced and the animal lives upon stored food. Thus, the leopard frog develops fat bodies and stores glycogen, which furnishes energy for metabolism during hibernation. Warm-blooded animals which hibernate include the familiar woodchucks and the ground squirrels. During hibernation of one species of ground squirrel the pulse is reduced from 200 to 4 beats per minute. Breathing becomes almost unnoticeable, and the body temperature is reduced from 105° F. to about 58° F. The reduction of the rate of metabolism enables the animal to live upon a smaller amount of stored food material than would be the case if metabolism remained normal. Other mammals that become more or less inactive during very cold weather include chipmunks, various species of squirrels, racoons, and bears.

Æstivation. Æstivation occurs among some animals living in tropical or semitropical climates. During the warmer weather these animals become torpid or inactive, and are said to be æstivating.

Lungfishes. The lungfishes are represented by four species, found in Africa and South America. These fishes, as the name indicates, have lungs. During the wet season they live in the water. During the dry season, however, they work their way into the mud at the bottom of the drying ponds and marshes, and remain in a semidormant condition, living upon stored food materials in their bodies.

Migration of salmon. Some animals migrate, probably for a variety of reasons, some of which are not definitely known. The Chinook salmon of the Pacific Coast region performs an interesting migration, which results in the depositing of its eggs in places which prove to be fairly safe environments for the young.

Although the Chinook salmon is hatched in fresh water, the adult lives in the sea for several years before taking part in a "salmon run" or migration. Each year a number of adults gather in the bays along the coast and then take part in a "run." This "run" is a migration up to the quiet pools at the headwaters of the streams which empty into the ocean. Both male and female salmon take part in these migrations, some of which



Acme.

FIGURE 153. Salmon ascending rapids in a stream. What life function is the basis of this type of migration?

are over a thousand miles in extent. The adults do not take food while migrating, and are usually in rather worn and battered condition when they reach their destinations.

Here the females deposit their eggs upon the sandy bottoms of shallow pools. Both the adult males and the adult females then die. The eggs hatch late in the summer and the young salmon gradually work down the streams to the ocean.

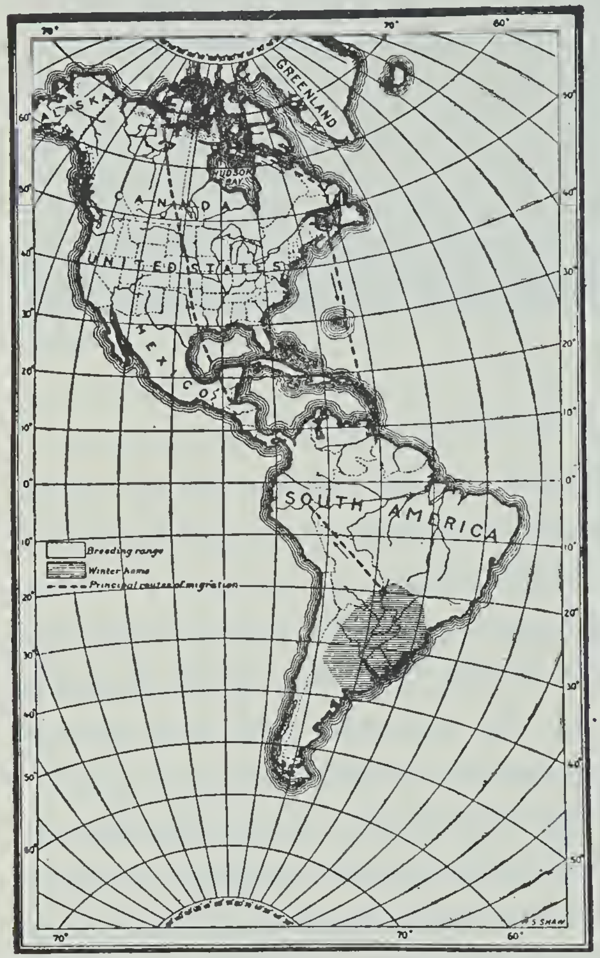
Migration of lemming. Among mammals, some species of bats, reindeer, fur seals, and a few other types undergo migrations. An unusual case is presented by a species of lemming (a type of rodent) which is found in Sweden and Norway. According to one authority, these lemmings become very numerous at intervals of about twelve years. Then a large group of the rodents begin a migration toward the seacoast. They swim across lakes and rivers — even pass over mountains. Many of them are killed en route. When the survivors reach the sea, they swim out from the shore, and eventually are drowned.

Insect migrations. Grasshoppers, crickets, army worms, and some other insects also develop migratory habits when they become unusually abundant in a certain region. Such migrations usually are of great importance from the standpoint of agriculture.

Bird migration. Of course many species of birds migrate in the spring and again in the fall. This phenomenon has been studied rather extensively, yet a number of questions have not been answered satisfactorily. Several reasons have been suggested as to why birds migrate. These include the following possibilities:

1. That migration represents an effort to secure food under the most favorable conditions.
2. That it is a matter of remaining in a warm climate.
3. That birds migrate away from the tropics in order to secure safer nesting places.

There is also the question as to how birds find their way across regions that are vast in extent. It has even been suggested that they may possess a sense of direction.



American Museum of Natural History, New York.

FIGURE 154. Map showing the migration routes of the golden plover. How do you suppose that these routes became known to man?

Migration of the golden plover. The golden plover performs one of the classic bird migrations. In the summer it nests upon the shores of the Arctic Ocean. In late summer the birds move southward and eastward to the region of Labrador. Then they start southward across the Atlantic Ocean and may not be in touch with land again until they reach the Lesser Antilles or the northern coast of South America. Arriving in South America they pass on to the region of southern Brazil where they remain for a time. During the spring migration the birds of this species pass northward through South America, Central America, the Mississippi Valley, and Canada, to their summer homes.

Other bird migrants. The migration of the golden plover is more extensive than that of many birds. A number of our common summer birds in the United States spend the winter months along the Gulf Coast or in the West Indies. However, some twenty species of warblers reach South America during our northern winter. On the other hand, some birds do not migrate except for local movements in search of food, nesting places, and the like.

Summary. In conclusion, we see that there are many different kinds of adaptations. They are exhibited by all organisms. Some of them are adaptations of structure and some have to do with behavior, which in turn is influenced by structure. Some have to do with various habitats, others with protection, others with obtaining food, and some represent responses to seasonal changes. As to how adaptations of structure originate, the best answer probably is that many of them have resulted from the actions of variation, selection, and heredity. We should remember that adaptations of structure (including color) are not volitional (controlled by the will). In such cases organisms *become* or *are* adapted; they do not adapt themselves. Such problems will be discussed more fully in a subsequent chapter.

SUGGESTED ACTIVITIES

Scientific methods

A scientist classifies and arranges specimens for reference in future work.

1. Examine museum materials, or materials collected in the field for cases of special adaptation, as described in this chapter.
2. After reference to a botany textbook, prepare a report on defense structures of plants, such as spines or thorns.

3. Prepare a glass-enclosed box, in which you mount some example of an organism together with its environmental setting. Insects probably are most available and easiest to collect and mount.
4. Prepare a chart in colors of some example of protective resemblance or mimicry.
5. Prepare a map of the Western Hemisphere; on it trace the routes followed by the golden plover in its seasonal migrations.
6. Self-testing exercise: Select the definition from group B which best fits each of the items in group A.

A	*B*
Organism	1. parasitic upon an animal
Fauna	2. animal population of a region
Flora	3. eats only plant food
	4. plant population of a region
	5. any living thing

7. Compare the bills of a duck, hawk, owl, robin, warbler, vireo, house sparrow, heron, woodpecker, snipe, and parrot. Indicate special uses of the bill in each case.
8. Compare the feet of a hawk, owl, duck, loon, heron, robin, chicken, and woodpecker. Indicate special uses of the feet in each case.
9. Self-testing exercise: Copy the following terms in a vertical column on a piece of paper. After each term write the name of an animal or plant that illustrates the meaning of the word. Aerial, aquatic, semiaquatic, arboreal, carnivorous, omnivorous, herbivorous, parasitic, saprophytic, subterranean, terrestrial.

SUMMARY OF PRINCIPLES

1. Many organisms exhibit adaptations for life in different environments; some adaptations are structural and some are functional.
2. Structural adaptations serve to classify animals as terrestrial, aquatic, arboreal, aerial, and subterranean.
3. Animals exhibit a variety of special adaptations for obtaining food.
4. Protection from enemies is achieved by a wide variety of adaptations among different species.
5. Certain adaptations are concerned with protection of the young.
6. Some species exhibit marked changes of behavior in response to seasonal changes, or other changes of the environment.

GUIDE QUESTIONS

1. Name three organisms adapted to arboreal life. Discuss the structural adaptations involved.

2. Compare the adaptations for flight possessed by bats, birds, and insects.
3. Mention two or more adaptations of each of the following for aquatic life: duck, frog, fish, and whale.
4. Give four examples of special adaptations of different animals for securing food.
5. Describe the protective coloration of the dead-leaf butterfly.
6. Explain the defense adaptations of: (*a*) a squid, (*b*) a porcupine, and (*c*) the hermit crab.
7. Name five defense or protective adaptations other than those mentioned in questions 5 and 6.
8. Describe the adaptations of kangaroos for protection of the young. Name another animal that has the same sort of adaptation.
9. What is hibernation? Give an example. How does it compare with æstivation?
10. What is meant by "migration"? Name three animals that migrate.
11. State three possible reasons for the seasonal migration of birds.
12. In the United States, at which season do ducks: (*a*) migrate north, (*b*) migrate south? Explain this flight as you understand it.

BOOKS TO READ

Chapman, F. M. *Handbook of the Birds of Eastern North America.*
Hegner, R. W. *Parade of the Animal Kingdom.*
Mavor, J. W. *General Biology.*
Rowan, William. *The Riddle of Migration.*
Woodruff, L. L. *Foundations of Biology.*

UNIT V

REPRODUCTION

REPRODUCTION is a life function which has been reserved for special study in this unit. It concerns the production of new individuals. No species can continue to exist unless new members of that species are produced and grow to maturity.

In the course of our study we shall learn that "all life comes from life." All species reproduce. Reproduction is not successful unless new individuals grow to maturity and reproduce in turn. We know that some species produce relatively large numbers of offspring. Other species reproduce at a relatively slow rate. Are these facts of any significance?

We shall find that growth is related to reproduction. Life cycles vary in different species. The exact method of reproduction also varies. Many complex organisms begin life as single cells. On the other hand, there are some interesting variations in certain reproductive processes. What, for instance, is involved in vegetative propagation, or in regeneration?

Our study of the sex cell in division will involve the discussion of chromosomes and genes. What are chromosomes and genes? How are they related to the processes of heredity? What disposition is made of the chromosomes in cell division?

Spore formation is a common phenomenon among plants. We shall also learn that many plants undergo sexual reproduction. Our studies will naturally bring us to the consideration of flowers and seeds. What are the essential structures of flowers and seeds? What are some of the adaptations and agencies that are involved in the dispersal of pollen and seeds? Are there any similarities between sexual reproduction in plants and sexual reproduction in animals? Do the higher plants reproduce only through the medium of seeds?

When we study the reproductive processes of animals we shall find that some of the simpler types reproduce asexually. Sexual reproduction, however, is very common, and is even represented among some of the simpler animals. Some species reproduce both by asexual and sexual methods. We shall wish to investigate some of the stages in the development of an animal from a fertilized egg. How is this accomplished? Is there any common pattern of development? Our study will be concluded by considering some cases of reproduction among animals. We shall attempt to answer some of the following questions. How are sponge colonies formed? How many eggs are produced by such animals as the female oyster? Do any insects bear their young? Do all reptiles, such as snakes, lay eggs? Do any mammals lay eggs?

CHAPTER XXII

THE CONTINUITY OF LIFE

Problems:

1. Does all life come from life?
2. Do all organisms reproduce?
3. Is growth related to reproduction?
4. What are the general types of reproduction?
5. What are the processes involved in sexual reproduction?

ALL LIFE COMES FROM LIFE

Foreword. Suppose it was proposed that a group of science students debate the question, "Can life *originate* in soup which has been heated until it is sterile, and then sealed in a glass container?" It is doubtful if anyone could be found to support the affirmative. Scientists do not decide questions upon the basis of opinion; they attempt to get facts upon which to base conclusions. One of the first proposals probably would be "let us perform an experiment designed to obtain the important facts which relate to the problem."

To us this seems the natural way to determine the answer to such a question. However, this has not always been the case. The ancients believed that frogs were generated from mud, and that maggots grew spontaneously in spoiled meat. In the seventeenth century, Francesco Redi (1626–1697), a scholar with a practical turn of mind, made an experiment. He covered some meat with gauze, and by thus preventing flies from reaching the meat, he showed that no maggots developed. This did not convince everybody. In the eighteenth century scholars continued to debate the proposition of the spontaneous generation of life.

Louis Pasteur. It remained for the remarkable experimenter, Louis Pasteur (1822–1895), to settle the matter. He placed some sterile broth in special flasks having long, swan-neck tubes. These flasks permitted air to enter, but prevented the entrance of dust containing bacteria or spores. In such flasks no organisms appeared in the sterile broth, and the broth did not undergo spoilage. In control flasks into which dust containing organisms could fall, the broth soon spoiled, and the microscope revealed the presence of numerous bacteria.

Since Pasteur's time, abundant evidence has convinced scientists that "all life comes from life." The study of reproduction is closely related to the study of cells and the cell principle. After all, reproduction depends upon the division of cells. No new organism is produced that does not result from the division of a cell or cells of a parent, or perhaps two parents.

This concept, in turn, is related to the cell concept — that all organisms are composed of cells, and that all life processes represent the activities of cells. The concept that all life comes from life sometimes is stated as part of the cell principle. New organisms result from the activities of cells which come from parent organisms.

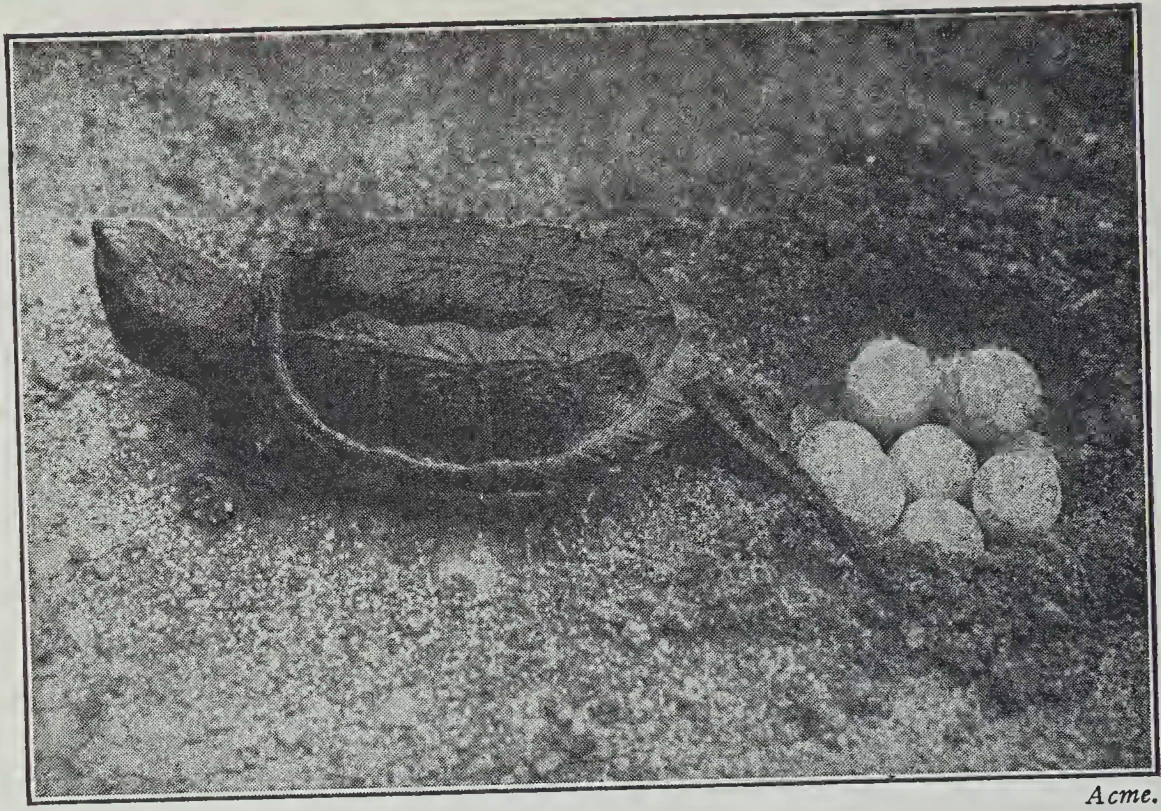
REPRODUCTION IS A FUNCTION OF ALL ORGANISMS

We may classify the activities of organisms in two general groups for the sake of convenience. In the first place, there are those activities which are concerned with the survival of the individual organism. These include special adaptations for defense and for obtaining food. They also include the carrying-on of ordinary life functions, such as obtaining food, digestion, absorption, response to stimulation, respiration, and excretion.

Reproduction and the species. In the second place, organisms reproduce, and this provides for the continuance of the race or species. Various methods of reproduction are found among different organisms. We find that reproduction may be sexual in some cases and asexual in others. But although the method varies, reproduction is a function of all organisms. It results in the production of new individuals,[1] and this tends to continue the species from generation to generation.

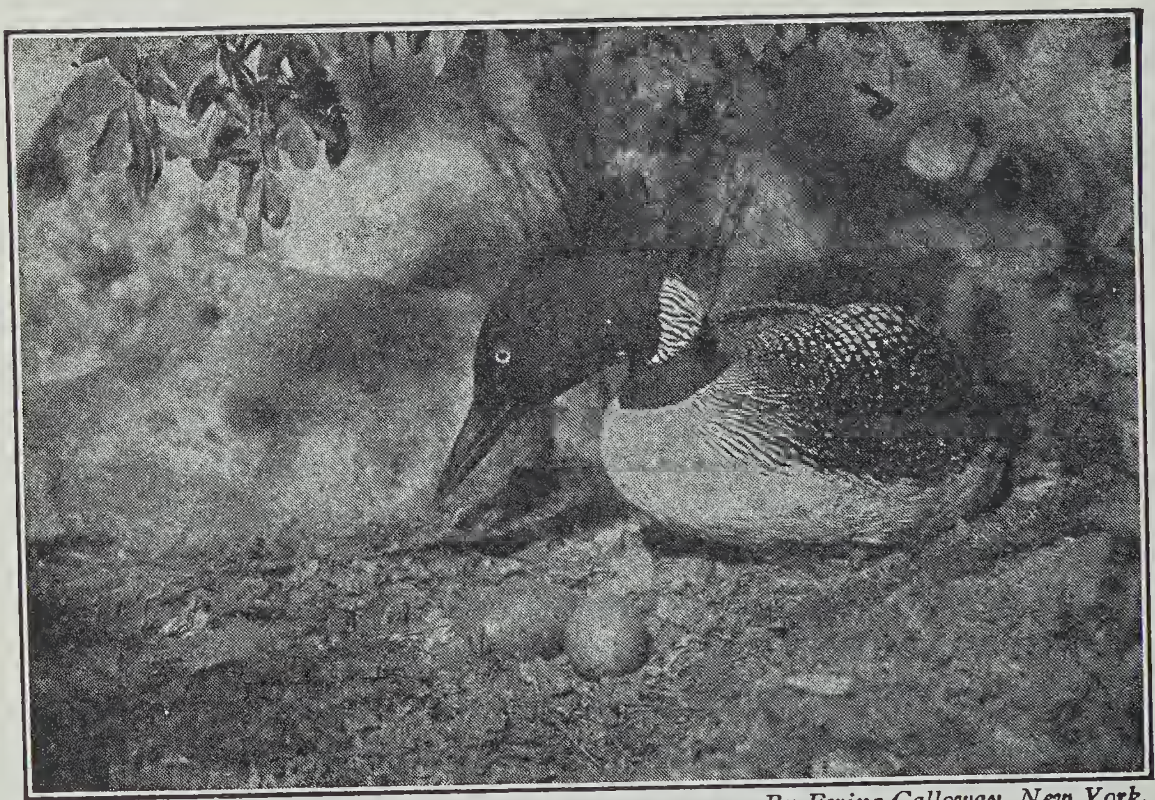
In the preceding unit we found that some species have special adaptations for the protection of the young. Other species

[1] An individual, as here used, refers to a single member of any species.



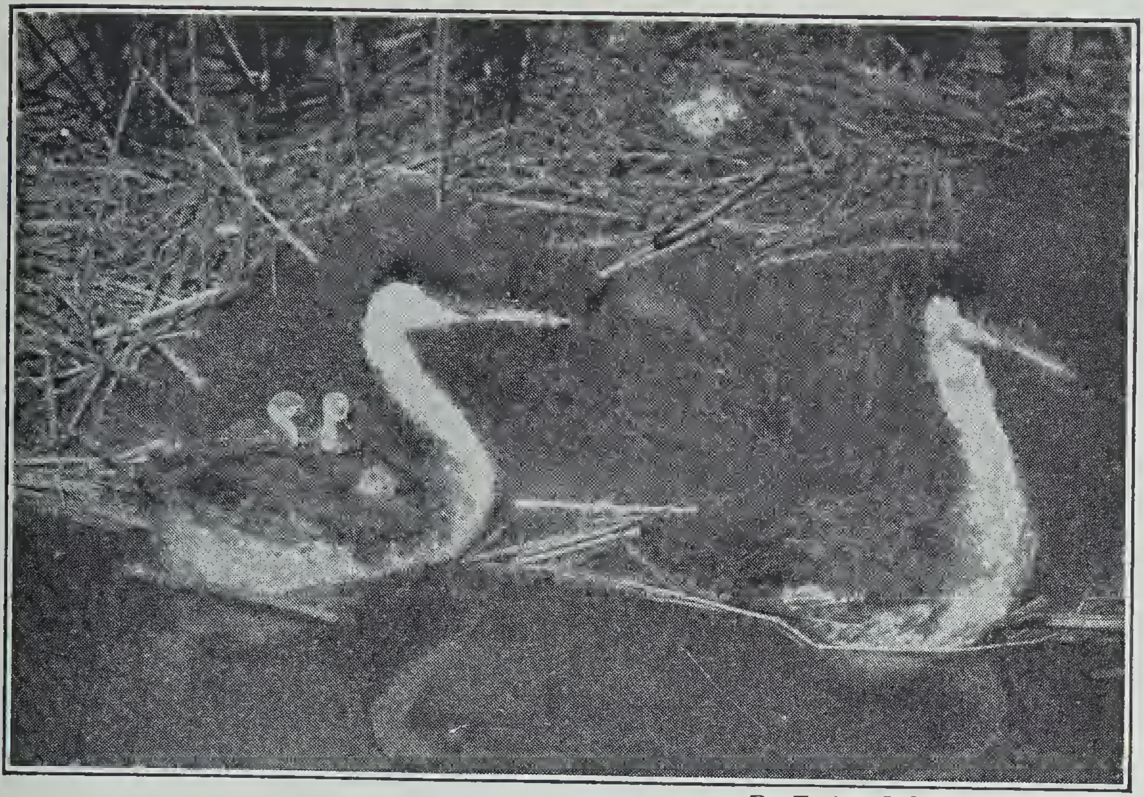
Acme.

FIGURE 155. A snapping turtle and her eggs. Does a turtle give any care to the eggs or the young turtles? How are the eggs kept warm during the period of incubation?



By Ewing Galloway, New York.

FIGURE 156. A loon, with nest and eggs.



By Ewing Galloway, New York.

FIGURE 157. A pair of grebes and their young. Note the novel means of transportation.

may deposit their eggs in places where the latter are relatively safe. The eggs may be deposited in places where food probably will be available for the young. Animals which provide parental care for the young often produce relatively few offspring. However, in the latter case, a comparatively large percentage of the offspring may become adults. On the other hand, some species provide no parental care for their offspring. In such cases, large numbers of offspring are often produced, but only a small percentage of these offspring are likely to become adults. If reproduction is to be successful, new individuals must grow to maturity in order that they also may reproduce. In many species which reproduce rapidly the individual has a relatively short life.

Reproduction — a function of all organisms. Although methods of reproduction may vary, we find that reproduction is a function of all species. It is a necessary function if the species is to survive. The success of a species depends in part upon the success of its reproductive process.

Growth and cell division. When cells reach a certain size, which varies according to the type of cell and the species, they are said to be mature. Nutrition does not cease, however, and such a cell may now subdivide into two cells. When the cell is an individual organism like Paramecium or Pleurococcus, this division is called reproduction. New individuals are produced as a result of the division.

In organisms which are composed of many cells, various body cells grow to maturity and divide. Thus various structures may increase in size, and cells which have been destroyed are sometimes replaced by new cells. We see evidences of this process when the end of a root becomes longer, when new shoots appear on a branch, or when fingernails grow. All of these processes are dependent upon cell division, and the production of new cells. Cell division, then, is not limited to sex cells. It occurs among many cells in the adult body.

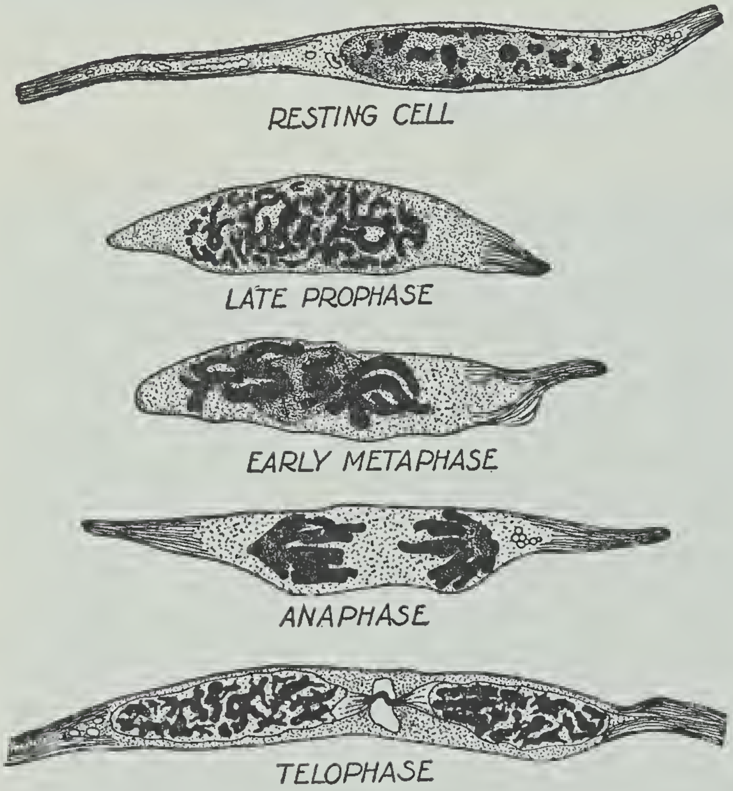


FIGURE 158. Mitosis in smooth muscle cells. (After Dr. A. W. Pollister.)

THE MICROSCOPE REVEALS HOW CELLS DIVIDE

How we study cell division. We have not as yet studied the process by means of which cell division is brought about. With the aid of the microscope we must look into the interiors of cells and study the structures which appear there. Actively growing plant tissue is often used as material for study. It is best to use a prepared slide for this purpose. Since the structures we wish to examine are very small, proper staining of the tissues is desirable if we are to see them clearly. Such a slide is made by slicing very thin sections of the tissue with an instrument known as the microtome. These sections are stained with one or more of a variety of chemical substances. All of the water is removed from the sections by treating them with alcohol solutions (in water), and finally with 100 per cent alcohol. Then the sections are treated with some clearing agent such as xylol. Finally they are mounted in balsam, which seals a section or sections between the slide and the cover glass.

Chromatin. If we look at such a prepared tissue with the aid of a microscope, we shall see that many of the cells are not in the process of division. In such cells we find a darkly stained, granular material in the nucleus. This deeply stained, granular material is called chromatin. The name refers to the fact that the granules stain more deeply than do other parts of the cell.

If we examine the tissue more closely, we may see cells in which the arrangement of material in the nucleus is somewhat different. In such a cell the chromatin material may be grouped together to form a threadlike structure known as a spireme. In another cell, the spireme may be broken into segments that are known as chromosomes. At this point in our study we should note that the material of which chromosomes are composed is chromatin.

Chromosomes. Chromosomes are very important in reproduction and heredity. Usually we do not expect to find the chromatin material grouped together in the form of chromosomes unless the cell is about to divide. Every organism in which chromosomes have been studied appears to have a definite amount of chromatin in all of its cells. When such chromatin becomes arranged as chromosomes, the number of chromosomes in each cell is normally the same for all members of a species.[1] Chromosomes are known to be the "bearers" of hereditary factors. Each chromosome appears to consist of units which are called genes. A gene is a hereditary unit, and has to do with the inheritance of

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[1] Certain exceptions are known, however. There are cases in which the number of chromosomes in a male cell differs from the number in a female cell of the same species.

TABLE V. NUMBER OF CHROMOSOMES IN DIFFERENT SPECIES

TYPE	NORMAL NUMBER OF CHROMOSOMES	TYPE	NORMAL NUMBER OF CHROMOSOMES
Man	47–48	Toad (Bufo)	24
Fruit fly (Drosophila melanogaster)	8	Pigeon (Columba livia)	16
Fruit fly (D. virilis)	12	Domesticated chicken	18
Ascaris (a roundworm)	4	Spirogyra neglecta	24
Horse	38	Oats (Avena barbata)	28
Grasshopper (Mecostethus)	23	Corn (Zea mays)	20
Anopheles mosquito	6	Domesticated dog	21–22
House fly	12	Frog (Rana fusca)	24
Evening primrose {Oenothera Lamarckiana}	14	Bullfrog (R. catesbiana)	26
Wheat (Triticum vulgare)	42	Onion (Allium)	16

some characteristic. Genes are not scattered about in a chromosome. According to evidence that has come from experiments, the genes are arranged along the long axis of a chromosome. It appears, then, that a chromosome is really a compound structure — it may include many units or genes.

Mitosis. When we find a case of cell division in which the contents of the nucleus behave in a special way, the process is termed mitosis. Mitosis, then, is a special type of cell division. Both body cells (somatic cells) and sex cells of various species are known to undergo mitosis. Many variations of mitosis are to be found among different types of cells. The following description will refer merely to mitosis in general.

The order of events within the nucleus during mitosis is about as follows. First, the chromatin granules come together to form the spireme. (See Figure 159.) Then the membrane around the nucleus (nuclear membrane) disappears. The spireme breaks up into segments which are the chromosomes. In the meantime two small structures in the cytoplasm called centrosomes have

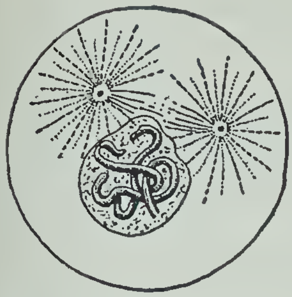

FIGURE 159. Diagram of the prophase in mitosis.

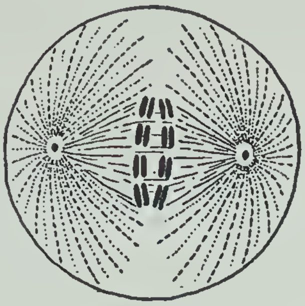

FIGURE 160. Diagram of the metaphase in mitosis.

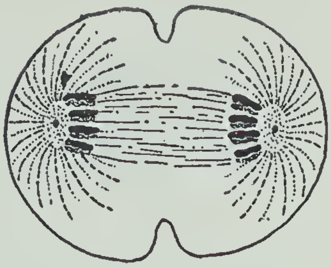

FIGURE 161. Diagram of the telophase (early) in mitosis.

moved to opposite poles of the cell. "Lines of force" appear and extend from the centrosomes to the nucleus. Exactly what the "lines of force" represent is not known. The central figure in the cell now resembles a spindle. The chromosomes become arranged end to end along the middle region of the cell. The events up to this point make up what is known as the prophase.

The chromosomes now may divide [1] along their long axes. This appears to be significant in view of the fact that the genes apparently are disposed along the long axes of the chromosomes. Half of each chromosome goes to one of the daughter cells.[2] Therefore, the division of chromosomes is equal, both as to quantity and as to quality. This stage of mitosis, involving the "splitting" of the chromosomes, is known as the metaphase. (See Figure 160.)

Two groups of chromosomes have resulted from the splitting process. These groups now move toward the centrosomes at the opposite poles of the cell. Meanwhile, the "lines of force" are becoming shorter and are tending to disappear. This is termed the anaphase.

In the final stages of mitosis, new nuclear membranes are formed around the two groups of chromosomes. The cytoplasm of the cell divides to form two daughter cells. These final events represent the telophase. (See Figure 161.)

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[1] In some cases the division is partial or complete before this stage is reached.

[2] The expression "daughter" has no reference to sex in this usage.

The four stages — prophase, metaphase, anaphase, and telophase, are recognized merely as a matter of convenience. They are not sharply separated stages, for mitosis is a continuous process.

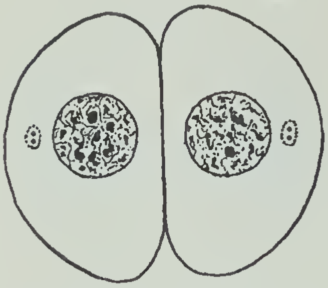
FIGURE 162. Diagram showing division of the cytoplasm in mitosis. (Late telophase.)

Students of the subject have observed cells undergoing mitotic division (mitosis) in various tissues of adult plants and animals. Many of these cells are body (somatic) cells rather than sex cells. We shall learn, however, that this type of cell division occurs in the division of fertilized ova.

A PERIOD OF GROWTH USUALLY PRECEDES REPRODUCTION

The life cycle. The course of an organism's life is called the life cycle. In general, it begins with a period of youth, in which growth and development take place. This is followed by a period of maturity, during which reproduction usually occurs. Then there is a period of decline or old age, which is followed by death.

We should recall that every step in the life cycle is not the same in all organisms. Amœba, for example, divides into two individuals upon reaching maturity. These two individuals begin the life cycle anew. In the case of any species, some of the cells of a mature organism are responsible for the development of offspring or young. Thus the descendants (cells) of these cells continue to live in future generations.

Growth and reproduction. It should be noted that growth usually precedes reproduction. In the case of Amœba, reproduction appears to be the natural end process of the growing period.

In more complex organisms, growth is made possible by division of cells within the body. The production of new cells often results in increased size. The division of cells within the body of the organism is in itself a phase of reproduction. It will be seen that growth of a cell precedes division into two daughter cells. In a complex organism the division of cells results in growth. Thus the two processes, growth and reproduction, are closely related to each other.

THE METHOD OF REPRODUCTION VARIES IN DIFFERENT SPECIES

Types of reproduction. In previous studies we have become conscious of the fact that there are various types of reproduction. In some of the lower plants, structures called spores are responsible for the formation of new individuals. Some simple plant cells merely divide to form two daughter cells. In other plants, individuals are observed to develop from runners or cuttings. These types of reproduction are asexual, although conjugation in some species, and spore formation, suggest the development of sex. In the spermatophytes (seed plants), seeds are produced from which come the new individuals. This latter type of reproduction is sexual, since seed formation involves the union of a sperm and an egg cell.

Among the lower animals, we find many cases of asexual reproduction. The simple fission of Amœba and the transverse fission of Paramecium serve as examples. Here again we must note that conjugation, which is known to occur in some protozoa, suggests the development of sex. Hydra presents an interesting case because it reproduces both sexually and asexually. The asexual reproduction of Hydra is commonly by budding, and less commonly by division through the long axis of the body. Sexual reproduction involves the production of sperms and ova.

Regeneration and reproduction. Regeneration sometimes results in the development of new individuals. In some plants, an entire individual may be developed from a portion of a root or cutting. The same result occurs among some of the lower animals. One species of Planaria may develop into two individuals when cut transversely into halves. Under favorable conditions an arm and a portion of the central disc of a starfish may regenerate into a complete animal. Such results represent asexual rather than sexual reproduction.

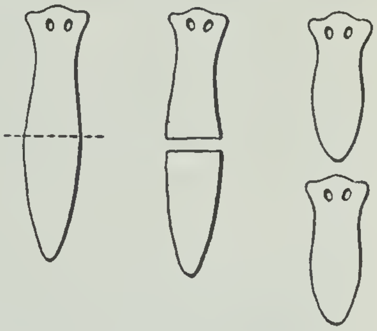

FIGURE 163. Diagram illustrating regeneration in Planaria.

Sperms and ova. It will be noted that sexual reproduction requires the development of two types of special cells, sperms and ova (egg cells). When a sperm and an ovum unite a fertilized ovum is produced. The fertilized ovum may now develop into a new individual. Since both sperms and ova are known as gametes, it may be said that the fertilized ovum represents the union of two gametes.

MANY INDIVIDUALS BEGIN EXISTENCE AS SINGLE CELLS

Many organisms begin their life cycles or existences as single cells. Exceptions to this general rule occur in the case of individuals which develop from runners or cuttings, or when regeneration produces a complete individual from a part of an organism, or in cases of budding and fission in such types as Hydra.

In the cases of Pleurococcus, Amœba, and Paramecium, it is self-evident that the individual begins life as a single cell. When we study reproduction in the higher plants, and in the higher invertebrates and the vertebrates, we again find that new individuals begin their existences as fertilized ova,[1] which are single cells. Let us now turn our attention to some of the factors in sexual reproduction. We should remember that this type of reproduction occurs among representatives of both the Plant and the Animal Kingdoms.

Maturation. A fertilized ovum, as previously stated, represents the union of a sperm and an ovum. But before sex cells may take part in such a union, each must go through a process known as maturation or reduction division. The sex cells often appear very early in the development of an organism. They may not become mature (undergo maturation) until a later time.

Pairs of chromosomes. In an unmatured sex cell, the chromosomes usually are present in pairs. One chromosome of each pair is derived from one parent of the individual in whose body the sex cell is found. Thus, if one chromosome of a pair is responsible for the inheritance of certain characters, the other chromosome of the pair usually has to do with the inheritance of the same characters. This is merely evidence of the fact that in sexual reproduction, the inheritance of an individual comes equally from each of two parents.

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[1] Or fertilized "egg cells" in the case of plants.

Now suppose that the number of chromosomes of a given species is eight. Then each unmatured sex cell will contain eight chromosomes. If two of these unmatured sex cells were to unite, as two mature ones do in fertilization, the result would be a cell containing sixteen chromosomes, whereas eight is the proper number for the species. What happens is that before fertilization occurs, each sex cell undergoes maturation. In maturation the number of chromosomes is reduced by one half.[1] Hence the mature sex cell contains half the number of chromosomes that is typical for the species. In the example we have used this number would be four.

Fertilization. In fertilization, a mature sperm and a mature ovum or egg cell, each containing half the typical number of chromosomes, unite. The fertilized ovum then contains the number of chromosomes that is typical for the species. Continuing our example, if the mature sperm contains four chromosomes, and the mature ovum contains four chromosomes, the fertilized ovum (or egg cell) will contain eight chromosomes.

The coming together of a mature sperm and a mature ovum may be a matter of chance, or there may be some chemical attraction of the sperm by the ovum. Perhaps this is a factor which varies according to species. At any rate, the ovum is large in size because it contains stored food. The sperm is small in size and often is able to move about in liquids because it may bear one or more flagella. Generally speaking, only one sperm may unite with an ovum. In some plants, after one sperm has entered an egg cell, the latter probably secretes a chemical substance which repels other sperms. In some animals, the cell wall of the ovum becomes thickened after a sperm has been admitted, thereby preventing the entrance of other sperms.

Division of the fertilized ovum. After an ovum has been fertilized it often enters a resting stage. Then after a period of time a mitotic division (mitosis — see page 360) occurs. The fertilized ovum divides to form two daughter cells.

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[1] There are a few exceptions — the sex chromosomes of some species.

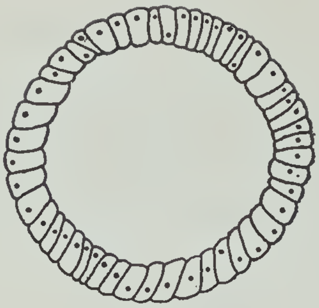

FIGURE 164. Diagram illustrating a cross section of a blastula.

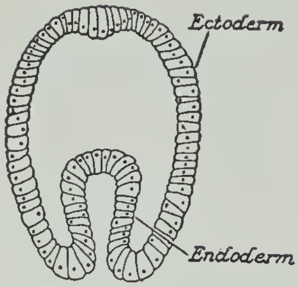

FIGURE 165. Diagram of a longitudinal section, illustrating development of a gastrula, as this process occurs in some animals.

The differences between maturation and mitosis should be clearly kept in mind. Maturation occurs both in the formation of mature sperms and the formation of mature ova. In maturation the number of chromosomes that is typical for the species is reduced by one half. Maturation always precedes the process of fertilization. Mitosis follows fertilization.[1] In mitosis a cell divides to form two cells. Each of the new cells contains the *full*[2] number of chromosomes that is typical of the species.

Early development. The two daughter cells that result from the first division of the fertilized ovum may enter a resting stage before division is resumed. Before the second mitotic division, the single centrosome of each daughter cell will divide to form two centrosomes. Other divisions of daughter cells result in the production of more and more cells, and early growth may be accomplished in this manner. Thus in some species the fertilized ovum divides to form 2 cells, the 2 divide to form 4, and then successive divisions result in the formation of 8, 16, 32, and 64 cells.

At one stage in early development many animals consist of a hollow sphere of from 32 to 128 cells. This stage sometimes is called the blastula stage. In a stage that follows the blastula, the developing body consists of two cell layers, one within the other. This is known as the gastrula stage. The outer cell layer is called the ectoderm, and the inner cell layer is the endoderm. Later in development, a third cell layer known as the mesoderm appears between the ectoderm and the endoderm. We shall learn more concerning these structures and processes of development in the chapter on Reproduction in Animals.

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[1] Body cells (other than sex cells) may also undergo mitosis. In this case fertilization is not involved.

[2] The normal number of chromosomes is often called "diploid," and the half number "haploid."

Summary. We have learned that reproduction is common to all organisms, although methods of reproduction vary. New individuals are produced and thus the species tends to be perpetuated. Fundamentally, reproduction depends upon the production of new cells — it is a cellular activity. Mitosis is a type of nuclear division which occurs both among body (somatic) cells and sex cells in many plants and animals. The chromosomes of the cells are the bearers of heredity. In most life cycles reproduction occurs during maturity, and thus follows a period of growth. Sexual reproduction involves the formation and activity of sex cells and occurs in representatives of both Plant and Animal Kingdoms. Asexual reproduction, also occurring in both plants and animals, is represented by such processes as fission, budding, regeneration, and vegetative growth.

In sexual reproduction the individual begins life as a single cell — the fertilized ovum. The chromosomes in the nucleus of the fertilized ovum are the bearers of hereditary characteristics. Each chromosome is composed of hereditary units called genes, which are arranged along its long axis. In mitosis, the chromosomes divide through their long axes and each daughter cell receives one half of the chromosome material. The repeated division of cells gives rise to a multicellular body.

SUGGESTED ACTIVITIES

Scientific methods

A scientist dislikes futile debate, and is willing to be convinced of error by evidence. He tries to avoid having his feelings influence his judgment.

1. Plan and perform an experiment of your own to show that maggots (fly larvæ) are not generated spontaneously, but hatch from flies' eggs laid upon organic material such as decaying meat.

2. Investigate by reading or observation (*a*) the average number of offspring, (*b*) the length of the period of immaturity, and (*c*) the probable number of offspring that reach maturity, in each of the following organisms: grasshopper, oyster, codfish, robin, rat, and elephant.
3. Investigate and report to the class the experiments of Tyndall upon the proposition of spontaneous generation. See *Fragments of Science*, by John Tyndall.
4. Examine slides with the aid of the microscope (demonstration) which exhibit cells in different stages of mitosis. Discuss what is seen in the light of what has been said about this process.
5. Examine examples of asexual reproduction which may be available, such as vegetative propagation among mosses growing in the school terrarium.
6. After consulting the reading references at the end of this chapter study charts, or prepare diagrams which illustrate the important phases of maturation, fertilization, and mitosis.
7. Define each of the terms in column A in a complete sentence, in which you use one of the descriptions from Column B.

A	*B*
Mitosis	1. Union of a mature sperm and a mature ovum
Maturation	2. Union of similar gametes
Fertilization	3. Development of mature sex cells
	4. Process of growing old
	5. Process of cell division

SUMMARY OF PRINCIPLES

1. All life comes from life.
2. Reproduction is a function of all organisms, which concerns the continuance of the species. To be successful, new individuals must grow to maturity, in order that they also may reproduce.
3. Parental care for the young is provided by some species. In the case of other species no parental care is provided, but large numbers of offspring are produced. In the latter case only a small percentage of the offspring are likely to survive.
4. Chromosomes are the bearers of hereditary characteristics. The units in heredity are the genes.
5. Mitosis is a type of cell division involving complex behavior of the chromosomes.
6. Growth normally precedes reproduction, and reproduction may be looked upon as an extension of the tendency for growth.
7. Reproduction is sexual or asexual, or of both types, in different species Both types of reproduction are sometimes represented in a single species.

8. Most individuals begin existence as a single cell — the fertilized ovum (or egg cell).
9. Maturation precedes fertilization. In maturation, the number of chromosomes in a sex cell is reduced to one half of the typical number.
10. Fertilization involves the union of two gametes, an ovum (or egg cell) and a sperm.

GUIDE QUESTIONS

1. What is meant by the expression "life comes from life"?
2. Discuss the distinction between "maintenance of the individual" and "continuance of the species." To what extent are they related?
3. Discuss what is meant by the terms "chromatin" and "chromosomes."
4. What are genes, and why are they of importance?
5. Are "growth" and "reproduction" related processes?
6. Define sexual and asexual reproduction. Do both types occur among plants? Among animals?
7. By what process does a sex cell become ready for fertilization? What is involved in this process?
8. In what respects do mature ova and mature sperms differ, and in what respect are they similar?
9. Explain the distinctions between mitosis, maturation, and fertilization.
10. How does a gastrula differ from a blastula?

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CHAPTER XXIII

REPRODUCTION IN PLANTS

Problems:

1. How is cell division related to reproduction?
2. Are there similarities between reproduction in plants and reproduction in animals?
3. How does pollination take place?
4. What are the structures of flowers and seeds?
5. What are the agencies involved in seed dispersal?
6. What asexual methods of reproduction occur among plants?

Foreword. Many visitors to the Century of Progress Exposition in Chicago brought back, as souvenirs, pieces of California redwood trees. These burls or knots of wood were interesting, because when put in a dish of water in a warm room they produced shoots which began to grow into trees when placed in the soil. Most people are familiar with the sprouting of seeds; farmers know that a potato plant may grow from a piece of a potato which includes an "eye," yet many people were surprised that trees could be developed from a piece of wood. How does such a phenomenon occur? Is this a normal method of reproduction among plants? In this chapter we shall be concerned with these questions, among others.

REPRODUCTION AND GROWTH DEPEND UPON CELL DIVISION

Reproduction and cell division. Our general problem is to study the principles of reproduction among plants. The growth of a new tree from a redwood burl involves these principles. We shall see that reproduction among plants achieves the same result as does reproduction among animals; namely, the continuance of the species. We also should note that regardless of what the method of reproduction may be, it involves the production of new cells. New cells result from cell division. Cell division is the basic process of reproduction. In the preceding chapter, we learned to call one type of nuclear division mitosis.

Mitosis in plants. The microscope fails to reveal the exact nature of cell division in all species. If the root tip of an onion (section) is viewed with the aid of a microscope, mitosis may be seen in a number of cells. Mitosis seems to be a common phenomenon in many growing plant tissues. On the other hand, in single cells, such as bacteria, the process is not so readily observable. We refer to division of such cells as being "fission." In the bacteria the type of reproduction represented is asexual. In most cells large enough to be viewed satisfactorily, however, some kind of mitosis seems to be involved in nuclear division.

Spores. In spore formation, another method of reproduction appears. A spore sometimes takes the form of a single cell with a thickened wall, which retains life amid adverse conditions. More often we find that spores are the result of the repeated subdivisions of the protoplasmic contents of a single cell. Sometimes four, eight, sixteen — even hundreds of spores may result from the division of one cell. Each of these tiny fragments (spores) may develop into an organism like the parent in all characteristics. Resting spores were noted among a few bacteria, and the common method of reproduction among fungi is generally by means of spores.

Whether or not this method of reproduction has limitations which make other means of reproduction desirable, we may not assert positively. However, the most successful plants supplement spore formation with sexual methods.

Advantages and disadvantages of spores. It can be seen that there are advantages in the method of reproduction by means of spores. First, there may be rapid multiplication of the species if all the spores germinate. Second, there is less chance of failure of reproduction when a great number of spores are formed. Wider scattering of the spores gives a better chance for each offspring to secure its nutritional needs. On the other hand, it is evident that spore formation subdivides the material of a cell into as many fragments as there are spores. It is possible that such repeated subdivision results in the development of less vigorous plants. If so, plants which developed adaptations for sexual reproduction might gain an advantage.

Conjugation. Most of the more complex plants exhibit sexual reproduction. Even most of the simpler types undergo processes which are suggestive of sexual reproduction. We may recall that Spirogyra, for instance, exhibits conjugation. Here we are able to observe that the contents of one of a conjugating pair of cells becomes condensed, and is emptied into the other cell which remains passive. These joining cells (gametes) form a zygote. This zygote may develop into a new filament of Spirogyra.

Maturated sex cells (animals and plants) are known as gametes. Thus we have female gametes (mature ova or macrogametes), and male gametes (mature sperms or microgametes). A fertilized ovum is called a zygote.

Sexual reproduction throughout the Plant and Animal Kingdoms involves the union of a sperm cell and an egg cell. But among plants, spore formation also is involved in the reproductive process. In many common plants there is a special body to bear gametes (gametophyte), and another form to bear spores (sporophyte). These forms alternate with one another in the life histories of these plants, and we have learned to refer to the process as alternation of generations.

If you study more botany you will learn many of the amazing ways in which plants bring about reproduction. We have noted some of them briefly in our study of the plant body. For the understanding that people other than botanists need, a few explanations will be sufficient. These explanations involve the processes of maturation, pollination, fertilization, seed dispersal, sprouting, and development.

PLANTS HAVE MANY ADAPTATIONS FOR POLLINATION

Pollination. In all seed-bearing plants the conspicuous body of the plant is the sporophyte. A tree is a sporophyte; likewise a grapevine and a bean plant. Most of our common seed plants develop conspicuous flowers. The flowers are made up of modified stems and their leaves, the latter becoming sporophylls and associated parts.

A stamen (microsporophyll) consists of a filament and an anther. On the anther, contained within little sacs, the pollen is formed. Pollen is a yellow powder consisting of small particles, which are spores (microspores). These spores alone are unable to grow into plants like the parent, but each must first grow into a gametophyte and produce sperm cells. The spores, moreover, can develop only in a moist, and usually nutritive medium. A suitable place for their development is furnished by the stigma of the pistil (megasporophyll) of a flower. This flower may be the same flower which produced the pollen, or it may be another flower of the same species.

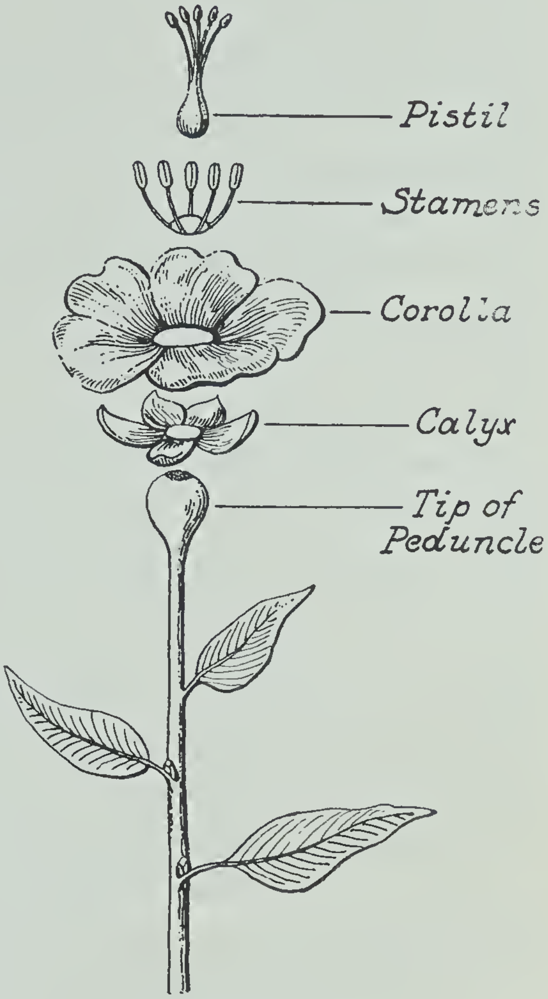

FIGURE 166. Diagram showing the structures of a flower. Which of these are essential organs of reproduction?

Pollination is the transfer of pollen from an anther to a stigma. Success is often attained by the action of external agencies. Adaptations of the pollen and of the flower structure assist in making use of these agencies.

Agencies in pollination. Pollen is moved through the actions of wind, water, animals, and gravity. It is light in weight and is often carried by air currents. This is a successful and common method of pollination. So abundant is this pollen in the air during the flowering season that it sometimes can be seen as clouds of dust. Autumn haze is due in part to pollen in the air. Pollen can be carried by water; a few water plants are pollinated as a result of this fact. Gravity, of course, causes pollen to drop from an elevated position to a lower stigma of the same flower, or to the stigma of another flower. Animals, especially insects, may act as carriers of pollen.

Plants which are pollinated by insects may have adaptations, such as the presence of nectar, which attracts some insects. Also, their flowers may be of such shape that the pollen must be rubbed against an insect when the latter enters or leaves the flower. Other adaptations which include sticky secretions, and the position of the stigma, provide that pollen from the insect is rubbed off on the stigma when the insect leaves or enters a flower. In addition, the insect which acts as a carrier often has structures which aid in carrying pollen. Hairy legs and body are such structures observable on bees and flies.

Cross-pollination. When the pollen of one flower reaches the stigma of the same flower, the process is called self-pollination. But in many cases very curious devices (adaptations) prevent this. When pollen from one flower reaches the stigma of another flower of the same species, the process is called cross-pollination. There are abundant evidences of the impossibility of self-pollination among many plants. Biologists believe, therefore, that cross-pollination may be of advantage in some way to the plants which possess adaptations for this method.

Among the various adaptations which serve to bring about cross-pollination are the following:

1. Some plants produce two kinds of flowers: some having only stamens and others having only pistils. Corn and cattails are of this type. Such plants are called monœcious ("one house").
2. Other species produce all staminate flowers on one plant and all pistillate flowers on another plant. Such plants are called diœcious ("two houses"). Willows and aspens are diœcious.
3. Another adaptation is seen in the location of the pistillate flowers higher on the plant than the staminate flowers. Hazel shrubs exhibit this adaptation. The same principle is shown in certain flowers whose stamens have filaments shorter than the pistil.

4. Still other flowers produce pollen which ripens and blows away before the stigma of its own pistil develops to maturity.

We see in all of these cases that pollination of a stigma by pollen of the same flower tends to be prevented. But it should be understood that some plants do reproduce successfully through self-pollination.

A complete flower. As we have noted, the essential reproductive organs of a flower are the pistil and the stamens. A complete flower, however, has also a floral envelope consisting of a calyx and a corolla. The calyx is the outermost, usually green, leaf-like part, sometimes tubular, and sometimes divided into segments called sepals. Next within the calyx is the colored portion of the flower, the corolla, which consists of petals. The petals, taken collectively, make up the corolla. We have described the stamens. Let us now examine the pistil. A pistil consists of one or more modified leaves (sporophylls), called carpels. Sometimes there are numerous pistils, each consisting of a single carpel, as in the buttercup. In other cases several carpels are joined to form a compound pistil, as in the apple.

A fully developed, single carpel (pistil), is made up of a lower, enlarged portion called the ovary, and a style, at the end of which the stigma is located. (See Figure 166.) The reproductive structures known as ovules are developed within the ovary. A megaspore is developed within each ovule.

SEXUAL REPRODUCTION IN PLANTS IS SIMILAR TO SEXUAL REPRODUCTION IN ANIMALS

Thus we see that the pistils produce megaspores, whereas the stamens produce microspores. Pistils and stamens are parts of the sporophyte plant. However, the megaspores and microspores now form female and male gametophyte generations. This process involves the germination of megaspores and microspores. It should be understood that the processes here described are typical of flowering plants. Many variations in details occur, however, among different species.

Pollen grains. A pollen grain is a single cell, and it may begin to germinate while still in the anther. Its nucleus divides to form two nuclei, and one of these nuclei again divides so that three nuclei are present. Two of these nuclei represent sperms. If the pollen grain is now transferred in some way to the stigma of a pistil, development will proceed.

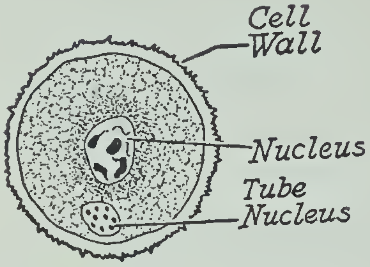

FIGURE 167. Diagram of a pollen grain.

The pollen tube. After reaching the stigma, if proper conditions are present, the pollen grain undergoes further changes. It develops a tube which grows down through the style. This is the pollen tube. Two of the nuclei which represent sperms are located near the tip of the pollen tube during its development. Each sperm nucleus contains half the number of chromosomes that is typical for the species. Hence we see that a reduction division such as that described under maturation has previously occurred. Finally the tip of the pollen tube enters the ovule case. Meanwhile the pollen grain together with its tube has become a male gametophyte.

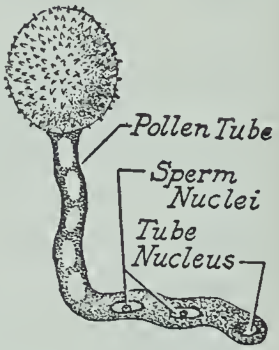

FIGURE 168. Diagram of a germinating pollen grain.

Development of the megaspore. Meanwhile, the megaspore within its ovule case has undergone certain changes. As a result of division a few cells (or sometimes only nuclei) are formed. One of these cells is a mature egg cell or female gamete, having half the number of chromosomes that is typical for the species. Again we may note that a reduction division has occurred. These few cells constitute the female gametophyte generation. The female gametophyte (in flowering plants), is very small in size, and like the male gametophyte can be studied only with the aid of the microscope.

Fertilization. In the course of development the pollen tube reaches and enters the ovule. Then one of the sperms (male gamete) unites with the egg cell (female gamete). The result is a zygote (fertilized egg cell), which contains the full number of chromosomes that is typical for the species. As in the case of sexual reproduction in animals, half of the chromosomes in the fertilized egg cell have come from the male gamete, and half have come from the female gamete. Again we find a striking similarity between sexual reproduction in plants and in animals.

Alternation of generations. We should not fail to note that alternation of generations occurs in the case of flowering plants. The sporophyte generation is comparatively large and conspicuous. It bears the flowers. We have noted that anthers and pistils are structures of the sporophyte generation. Anthers and pistils produce spores, known respectively as microspores (pollen grains) and megaspores. In the formation of these microspores and megaspores reduction divisions (of the chromosomes) occur. The microspores and megaspores germinate in or on the flower, and develop into male and female gametophyte generations, bearing mature sperms and egg cells.[1] The fertilization of a mature egg cell by a mature sperm marks the beginning of a new sporophyte generation. Thus the sporophyte generation produces a gametophyte generation, which in turn produces another sporophyte generation. The formation of the seed is the next step in development of the new sporophyte generation.

The seed. The fertilized egg cell (zygote) now undergoes mitotic division. Nutrition is derived from the near-by cells of the parent sporophyte. The zygote thus grows into an embryo, which is a young sporophyte plant. This embryo develops in a fashion somewhat like the cleavage process among animals, but without the distinct stages of blastula and gastrula.

Instead, there are formed, at one end of the embryo, the epicotyl or bud (plumule); at the other end the hypocotyl (root tip); and between the ends of this axis the cotyledons (embryo leaves). The cotyledons frequently contain stored food. In some seeds the endosperm which is a special tissue outside of the embryo, is formed in abundance. The endosperm is supplied with stored food. In any case a covering (testa)

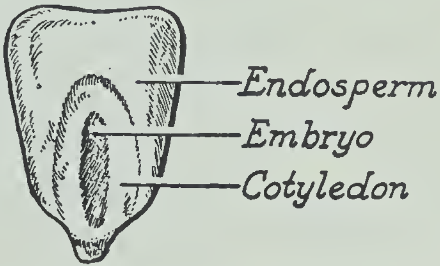

FIGURE 169. Diagram of a corn grain. Is this a monocot or a dicot?

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[1] Or only sperm and egg cell nuclei.

forms about the embryo and the stored food, and growth temporarily ceases. The seed consists finally of one or more seed coats, the embryo, and cells filled with stored food.[1]

Growth of seeds. The embryo is a miniature plant like the parent. Reproduction is completed. Growth into a mature plant may begin whenever suitable conditions occur. Usually a resting period follows seed formation. This resting period appears to be an adaptation to meet unfavorable climatic conditions. In the dry condition many seeds, beans for example, may be kept for a long time without destruction of the embryo.

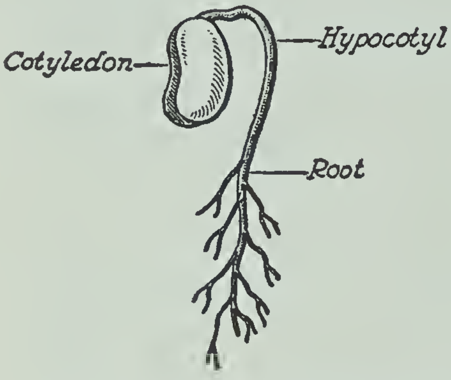

FIGURE 170. Diagram of a sprouting seed.

However, if a rainy season follows the production of seeds, they may grow immediately upon falling to the ground, or even within the ovary itself. The growth of a seed is called sprouting. The conditions necessary for sprouting include the presence of moisture, favorable temperature, oxygen, and in many cases a resting period. After the stored food of the seed is used, sunlight becomes necessary, and mineral salts must be present in the soil.

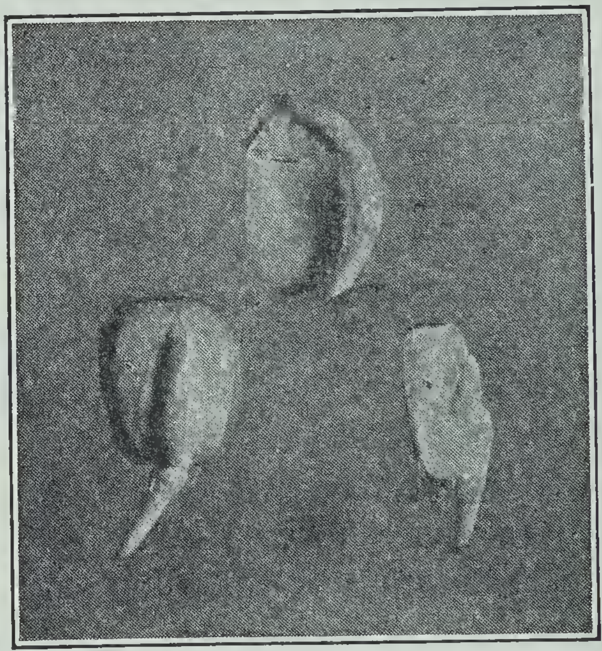

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FIGURE 171. Early growth of the seed in a bean, and corn.

PLANTS HAVE MANY ADAPTATIONS FOR SEED DISPERSAL

Fruits. A fruit consists of the enlarged walls of the ovary of a flower, together with other parts of the receptacle which may become attached to it. Thus the pod of a bean or a green pea, a tomato, a strawberry, an orange, or an apple are fruits, botanically speaking. The winged ovary of a maple also is a fruit. Within a fruit are, of course, the seeds. Fruits are adaptations "bringing about" protection and the scattering of seeds, thus aiding in perpetuation of the species.

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[1] Refers to seed of an angiosperm.

Seed dispersal. It is at once evident that if 5000 apples (not unusual) fell from a tree upon the ground, their seeds and the young plants developed from them would all be obliged to compete for the necessities of life. Sunlight, mineral compounds, air, water — all these would be in demand. It would be impossible for 5000 apple trees to germinate and grow to maturity in the small area beneath the parent tree. But the apple contains stored sugar, juice, minerals, and flavors. Bears, birds, horses, man, and many other animals use apples for food. The seeds are hard and bitter, and the animal ordinarily eats only the fleshy parts of the apple and discards the seeds. In many cases the seeds are carried away from the parent apple tree to a place where more favorable conditions for growth and less competition exist. This is an example of seed dispersal. Any means by which seeds are carried from the parent plant to other places is called seed dispersal.

Agencies in dispersal. Seed dispersal, like pollination, depends upon agencies which act as carriers. Adaptations of the seeds and fruits serve to bring this about. Animals, wind, water, and gravity are common agencies. Different fruits have a variety of adaptations which tend to bring about dispersal.

In the accompanying figure (Figure 172) you may see several fruits and seeds with structures which are favorable to dispersal by various means. Coconuts have a fibrous covering that allows them to float readily upon the water. Dandelions have tufted umbrella-shaped appendages that support the fruit in the air. Burdocks have hooks on the ends of the fruit that stick to the bodies of animals. Maples, hops, and elms produce winged fruits. Cotton and milkweed have seed hairs.

Some fruits open when ripe, and by various mechanisms discharge their seeds; violets and witch hazel are examples. It appears that plants which have adaptations for seed dispersal are

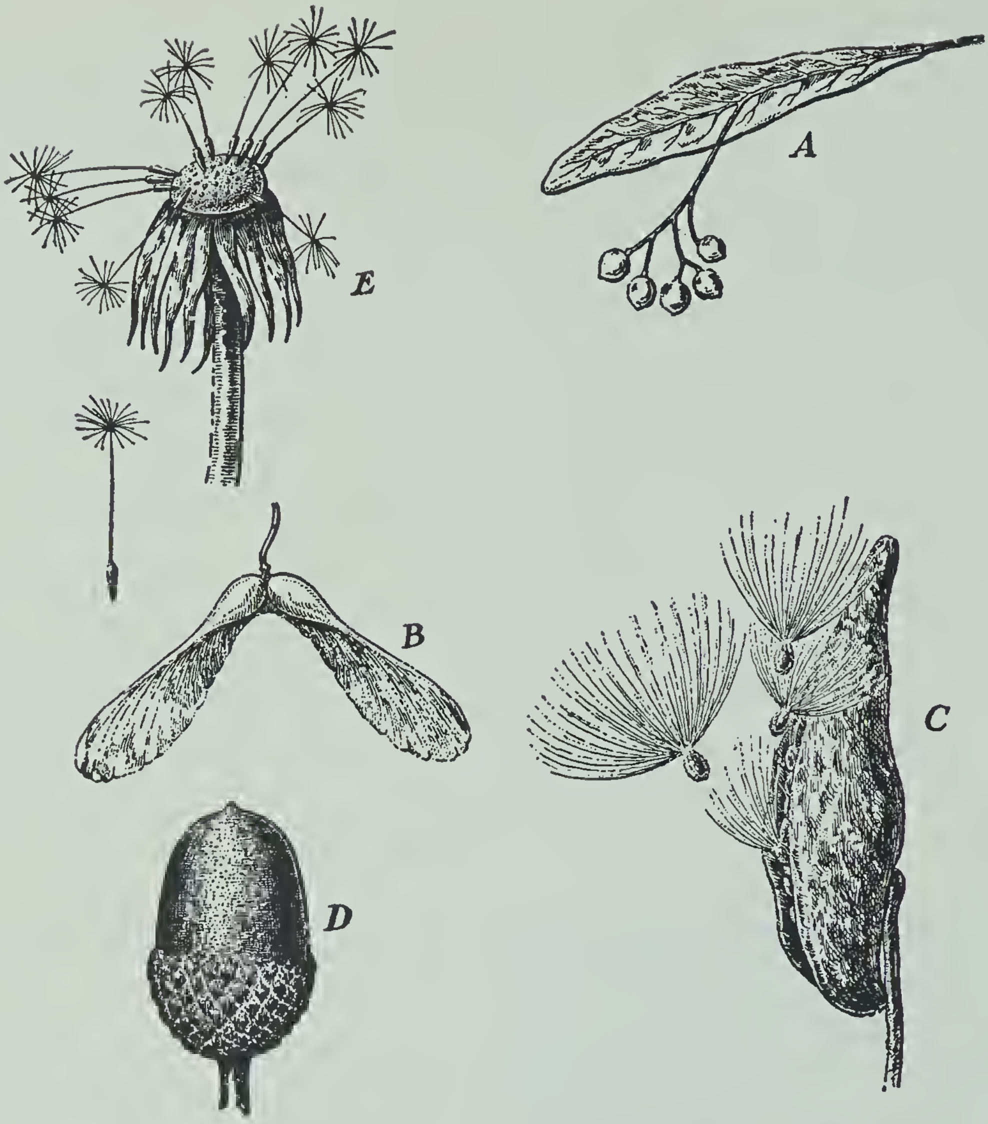

FIGURE 172. Some types of fruits and seeds: *a*, linden; *b*, maple; *c*, milkweed; *d*, acorn of an oak; *e*, dandelion.

the most successful in perpetuating themselves. The abundance of many weeds may be associated with the possession of such adaptations.

MANY PLANTS ARE REPRODUCED BY VEGETATIVE GROWTH

Other means of reproduction. While most of our familiar flowering plants reproduce in the manner just described, it is common knowledge that the "spreading" or multiplication of many plants is brought about by other devices. Sometimes

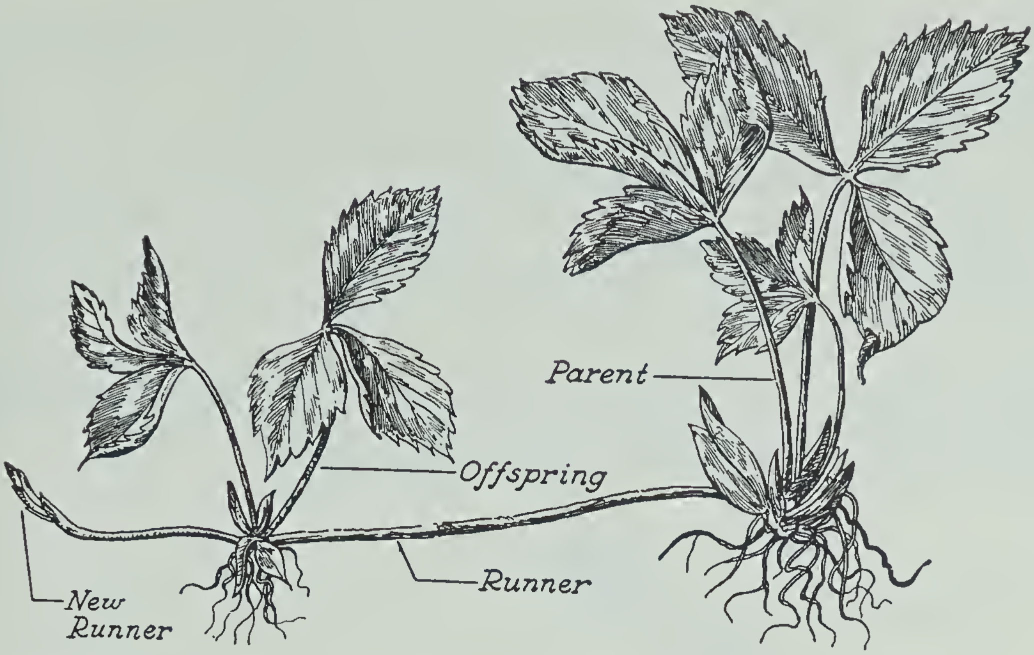

FIGURE 173. Diagram illustrating the development of a strawberry plant from a runner.

these are in addition to the sexual method just described. If you have tried gardening you may know that pieces of purslane, broken off in weeding, may take root again and form new plants.

Masses of seaweed (algæ) become larger because of vegetative growth. Beds of mosses increase in size when new individuals are formed by an asexual budding process.

Runners and stems. Likewise, strawberries develop runners in the late summer, and may produce many young strawberry plants from one parent plant. You may take slips from a geranium plant and place them in loose, moist soil, where they may develop roots. The florist makes use of the same method in growing many plants for the market. Grapegrowers often bury portions of living grape stems in the ground. New roots may be developed at the nodes upon the buried portion of a stem. Then this newly rooted stem may be separated from the parent plant, and may become a new individual.

Many raspberry bushes develop long, vinelike stems in late summer. These bend over and touch the ground, and they may form new roots at the point of contact. During the next growing season the stems connecting the newly rooted portions to the parent plants often are broken at some point. Thereupon the newly rooted portions become separate individuals.

Ferns and many grasses have underground stems which push out over large areas. At the nodes of these stems, buds develop and grow into aerial stems. Each of these buds therefore produces a new individual, which may become separated from the parent and continue to carry on an independent existence. All of the foregoing processes are examples of vegetative reproduction. They represent types of asexual reproduction.

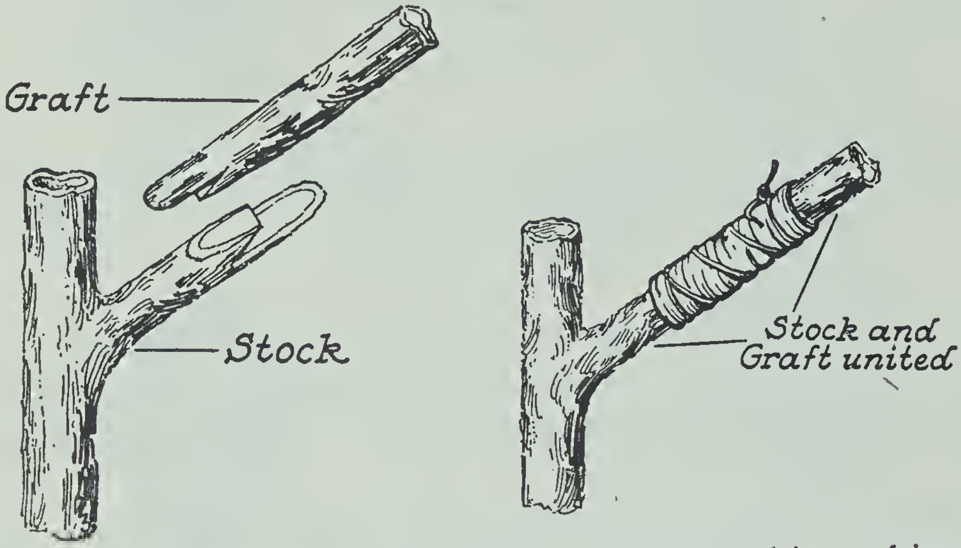

Figure 174. Diagram illustrating a method used in grafting.

Grafting. The word grafting, as colloquially used, means a sort of stealing or getting something for nothing. In plant propagation it refers to the fact that a graft often is a branch of a young plant attached to the stem of a more mature plant which furnishes the nourishment. In a certain sense, this is getting something for nothing. Many of our finest fruits are produced by grafting a branch or bud of a young tree of desirable variety upon the stronger, mature stem of a tree of inferior variety but of the same species (or related species).

Grafting consists of carefully making an incision in the mature tree, called the "stock," and of fitting into this incision the end of the freshly cut branch (called the "scion"). It is a delicate operation, involving the joining of the cambium of the stock with the cambium of the scion, and of holding them in place until the tissues unite. Many forms of joints are used; one of these is shown in the accompanying figure. (Figure 174.)

After the parts are properly fitted together, a bandage and grafting wax are firmly pressed around the joint, both to hold it in place and to protect it from insects, bacteria, or other injurious agencies.

Vegetative reproduction. We may define "vegetative propagation" as the development of new plants from roots, stems, leaves, bulbs, and such things as the thalli of algae or the protonema of a moss. Reproduction by this method among plants in their natural state is common. Some of the most successful spreading grasses, such as the Kentucky bluegrass, crowd out other plants by this method. Colonies of ferns, and of many weeds which grow in clumps, will be found upon examination to have resulted from this adaptation for vegetative reproduction.

The principle involved is easily understood. It is only protoplasm manifesting its function of growth. Extension of underground stems to wide areas has proved to be a useful adaptation for obtaining abundant food and sunlight. Hence plants having this adaptation tend to have survived. It seems apparent that plants which start with developed roots have an advantage over seedlings in overcoming competition for the necessities of life.

Man has made use of vegetative propagation in growing cultivated plants. For example, in Florida it was found possible to grow oranges much farther north by grafting the sweet orange upon the stocks of Japanese bitter oranges, which resist cold weather. Moreover, it has been discovered that there are certain advantages which accompany this general method. Some of these are:

1. Time is saved.
2. Plants can be propagated which do not produce seeds.
3. By grafting, a high quality of desirable fruit can be continued which does not "breed true" from seeds.

This last statement means that seeds do not always contain the "characters" which made the parent plant desirable. You will learn more about such characters when you study heredity.

Thus a seed from a large, juicy apple might produce a tree whose fruit was a small, dry apple, like that of some more remote ancestor.

Summary. In concluding our study of reproduction in plants we again may note that cell division is involved in this process. Mitosis may be noted in the case of many plant cells, as well as in that of many animal cells. We have observed that some of the lower plants reproduce by means of fission or by means of spore formation. Spore formation also is involved in the reproduction of higher plants, in which alternating generations, known as sporophytic and gametophytic generations, are developed. Among flowering plants we find many interesting adaptations relating to the process of pollination. In some species self-pollination is the rule; in other species cross-pollination occurs. Seeds represent embryo plants, together with stored food; fruits are mature ovaries and other attached structures. Many plants, including even some flowering plants, may be reproduced by vegetative growth or propagation. We find examples of this in the cases of mosses, ferns, bluegrass, strawberries, grapes, and raspberries. Man uses this knowledge in raising various desirable types of plants.

SUGGESTED ACTIVITIES

Scientific methods

A scientist may form hypotheses (guesses at the truth), and then test his hypotheses by experiment.

1. Unless this demonstration has been performed previously (see page 368), examine some slides of mitosis in onion root tips. With the aid of the instructor, identify cells in different stages of mitosis. Lantern slides exhibiting different stages of mitosis may also be available, or may be prepared as a special project.
2. With the aid of the microscope examine a slide of Spirogyra in conjugation. (See page 117.)
3. After consulting the reading references at the end of this chapter prepare a report on the adaptations for pollination exhibited by sweet peas, nasturtiums, and other flowers.
4. After consulting the reading references at the end of this chapter, prepare a report on the pollination of red clover.

5. Examine a flower, and identify various structures as described on page 375.
6. Examine sprouted bean and corn seeds. Identify important structures as described on pages 377 and 378.
7. Sprout various seeds in window boxes. By varying conditions of moisture and soil try to determine factors which are favorable to sprouting. Devise an additional experiment to determine whether or not light is necessary for the sprouting of the seeds.
8. Make an exhibit of several types of seeds or dried fruits which illustrate adaptations for protection and dispersal.
9. Make a chart of one of the following, after consulting the reading references at the end of this chapter:
   - *a.* Steps in the growth of a bean seedling.
   - *b.* Steps in the growth of a corn seedling.
   - *c.* Sketches of eight types of adaptations which facilitate seed dispersal.
   - *d.* Methods of joining a scion to the stock in grafting.
10. Prepare a demonstration of vegetative propagation, using willow stems, slips from a geranium, and ferns. This will necessarily require observation over an interval of weeks.

SUMMARY OF PRINCIPLES

1. Reproduction in plants, as in animals, is basically dependent upon cell division.
2. Mitosis occurs in many plants as well as in many animals.
3. Certain simple plants reproduce by spore formation. Some simple plants exhibit the phenomenon known as conjugation.
4. Spores are cells or fragments of cells which may be able to withstand adverse external conditions for long periods of time, and reproduce new individuals when favorable conditions arise.
5. Many plants may reproduce either by spores or by sexual methods, and often plants utilize both methods.
6. In the sexual method of reproduction among many plants, alternating generations are called sporophytes and gametophytes.
7. Pollination is the process of transferring pollen grains (microspores) from stamens to pistils.
8. Pollination usually is brought about through the agencies of wind, water, gravity, insects, and occasionally other animals.
9. Pollination is either self-pollination or cross-pollination.
10. Fertilization in flowering plants is accomplished by the growth of a pollen tube (containing two sperm nuclei) through the style and into the ovary, where a sperm nucleus unites with the egg nucleus.

11. Seeds are bodies consisting of a miniature plant, stored food, and a protective coat.
12. Fruits consist of matured ovaries together with other attached parts.
13. Reproduction ends, technically speaking, with the formation of the seed, which then may develop into a new individual by the process of growth.
14. Among some plants, many new individuals result from vegetative growth.

GUIDE QUESTIONS

1. How is cell division related to reproduction? to growth?
2. Discuss the advantages and possible disadvantages of reproduction by means of spores.
3. Describe the process of conjugation as it occurs in Spirogyra.
4. Explain the phrase "alternation of generations."
5. What is the lowest type of plant which we have studied that exhibited alternation of generations?
6. What is pollination?
7. Name four agencies which may serve to produce pollination.
8. Distinguish self-pollination from cross-pollination.
9. Describe a complete flower.
10. Describe the formation of a mature sperm cell in a plant.
11. Describe the formation of a mature egg cell in a plant.
12. Of what is a seed composed? A fruit?
13. Describe three adaptations of seed or fruit which aid in dispersal.
14. Explain the importance of seed dispersal.
15. Discuss several types of vegetative propagation. What uses does man make of this process?
16. Distinguish between the terms "mitosis" and "sprouting."

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CHAPTER XXIV

REPRODUCTION IN ANIMALS

Problems:

1. To what extent do animals reproduce asexually?
2. What is meant by "development"?
3. What is the significance of the three primary germ layers?
4. What variations in the method of reproduction do we find among animals?

Foreword. The fundamentals of reproduction in animals are similar to the fundamentals of reproduction in plants. At the same time, it is quite true that certain differences exist. Such differences, however, exist among members of the plant group alone. They also exist among members of the animal group.

It used to be a common superstition that "hair snakes" could be developed from horsehairs. Many of us remember one or more unsuccessful attempts to bring this about. Now we recognize that it is impossible; that in reality the "hair snakes" are slender roundworms which sometimes are found in the water.

Another question among boys who dug worms to use as fish bait was whether or not the pieces of a worm which had been cut in two would live and regenerate. By casual observation of various worms which had been so injured, it appeared that in some cases the cut ends healed and the worms continued to live. Other pieces were found dead and decaying after a few days had elapsed. We recognize this problem as one of regeneration, which involves matters of cell division and reproduction. Scientific study of regeneration in earthworms indicates that if a worm (Lumbricidæ) has the last twenty segments removed, the anterior end will survive and regenerate in most cases, if placed in a favorable environment.[1] The posterior portions live for a time, but eventually die. Anterior ends of the body also survive and regenerate new segments when the body is cut into two equal portions. In this case also the posterior ends fail to survive.

In this chapter we shall examine reproduction among animals. We shall begin by considering reproduction among some of the lower types. As we proceed, we shall note some of the interesting variations which occur among the various forms of life.

ASEXUAL REPRODUCTION IS COMMON AMONG THE SIMPLER ANIMALS

Asexual reproduction among single-celled organisms. We have seen that some single-celled plants and single-celled animals reproduce by means of fission. In some cases this appears to represent asexual reproduction. Even many-celled animals, such as some sponges, Hydra, and some flatworms, may reproduce by various kinds of fission. In these cases, however, the animals also have sexual methods of reproduction.

Protozoa and metazoa. Now as far as animals are concerned, the protozoa are set apart from all other animals by the fact that they are single-celled. It is true, of course, that there are some colonial protozoa, but in such cases they represent groups of single cells rather than organized bodies in which there is extensive division of labor. The animals whose bodies consist of many cells are known as the metazoa. Hydra is a simple type of metazoan. Earthworms and frogs are more complex types of metazoans.

Reproduction among metazoans. As has been suggested in foregoing descriptions, some of the metazoans reproduce asexually. We have examples of this in the case of budding and fission in Hydra, fission and regeneration in Planaria, and regeneration in starfishes. But the more complex metazoans tend to reproduce by the sexual method. In mammals, birds, reptiles, amphibians, and fishes, reproduction is sexual and involves such processes as maturation, fertilization, mitosis, and development. In the following pages we shall describe some of the variations in the reproductory process as they occur among different animals.

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[1] Fitzpatrick, F. L. "Relative Ability of the Anterior and Posterior Ends of the Body to Regenerate in Earthworms." *Proceedings*, Iowa Academy of Science, vol. 36, 1929.

Hermaphroditic animals. Among some metazoans, and especially the less complex types, the reproductive organs of both sexes may be present in one individual (hermaphroditic or monœcious). This is the case in Hydra, in Planaria, and in the earthworm.[1] However, this does not always mean that the ova of one individual will only be fertilized by sperms from the same individual, as evidenced by cross-fertilization in the case of an earthworm. In vertebrates, the individual generally is either a male or a female, and cross-fertilization is the rule.

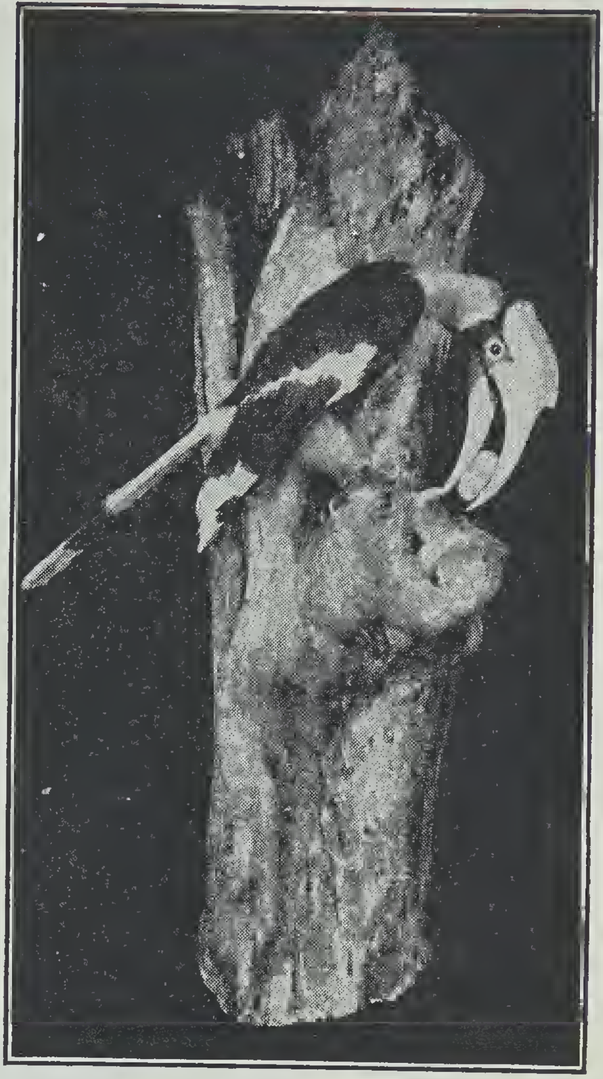

FIGURE 175. A male Siamese hornbill feeding his mate. The female is sealed in her nest (except for a small opening used for feeding purposes) during the hatching period. (Courtesy of Professor H. R. Dill.)

DEVELOPMENT DEPENDS UPON DIVISION OF CELLS

Cleavage. In a previous chapter we have studied the earlier phases of sexual reproduction, including maturation and fertilization. Let us now give more careful attention to the processes of development. After a fertilized ovum has begun to divide, and until the blastula stage is reached, it is said to be undergoing cleavage. This means that the cells are undergoing successive divisions and generally remaining attached to one another. Cleavage is not the same in all animals, but the result in all cases is the production of a blastula. Let us now examine a simple type of cleavage, such as that of a sea urchin, an animal related to the starfishes.

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[1] Lumbricus terrestris.

Cleavage in a sea urchin. In a sea urchin, the fertilized ovum divides to form two equal daughter cells. This represents the first cleavage. In the second cleavage the two cells divide to form four cells. The third cleavage produces eight cells, and so on. After the fifth cleavage (thirty-two cells), the new individual has reached the blastula stage, and consists of a hollow sphere of cells. The wall of this sphere is one cell layer in thickness.

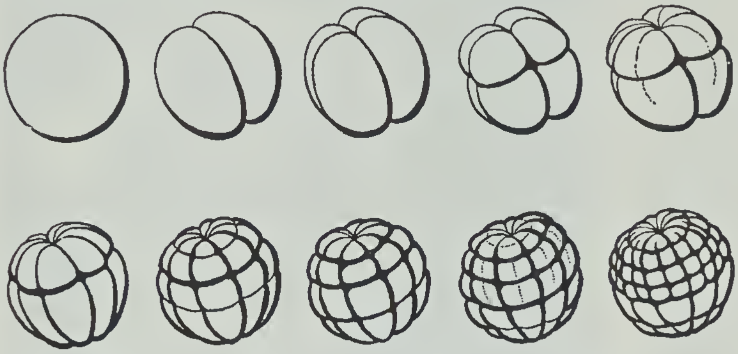


FIGURE 176. Diagram showing cleavage of a frog's egg.

The blastula and the gastrula. It should be observed that the blastula contains a hollow cavity. Now as development continues and more cells arise through subdivision of former cells, one side of the blastula begins to push inward, gradually eliminating the cavity of the blastula. This is the way in which the gastrula is formed in this type. (See Figure 165.) The gastrula has two cell layers, known as primary germ layers. The outer layer is the ectoderm; the inner layer is the endoderm.

THE THREE PRIMARY CELL LAYERS GIVE RISE TO THE SAME STRUCTURES IN MOST ANIMALS

Ectoderm and endoderm. The gastrula, with its outer layer of ectoderm, its inner layer of endoderm, and its primitive digestive cavity is not unlike an adult Hydra. In fact, a Hydra is little more than a gastrula.

The mesoderm. In a sea urchin and higher animals, development includes the formation of a third primary germ layer, the mesoderm. This layer develops between the other two layers, and often is formed from cells that originally come from both the ectoderm and endoderm.

Other types of cleavage. In other forms of animal life cleavage is not always equal, nor is the blastula or the gastrula formed in the foregoing manner. In some cases cleavage may be unequal, in which case large and small cells, instead of equal cells, are formed. Other types of cleavage are known to occur among higher animals. The study of these phenomena, however, may be deferred until a later time.

Three primary germ layers. The three primary germ layers (ectoderm, mesoderm, and endoderm), although relatively unspecialized themselves, are of interest to us because in most animals they give rise to the same specialized adult structures. Thus the nervous system, the outer layer of the skin (epidermis), and the external skeleton (hair, feathers, scales or plates), come from the ectoderm in the process of later development. The mesoderm gives rise to the different types of muscle tissue, the internal skeleton, and the sex cells. The endoderm forms the epithelial linings of internal organs — the lining of the stomach or small intestine serving as an example. In a higher animal, growth and development beyond the gastrula stage involves both increase in the number of cells, and specialization of cells resulting in the formation of tissues, organs, and systems.

SPECIAL TYPES OF REPRODUCTION ARE FOUND AMONG MANY SPECIES OF ANIMALS

Sponges. We pass now to a study of different types of reproduction, as illustrated by different forms of life. Certain marine sponges may furnish our first example. Some of these sponges live as separate individuals; other species develop colonial growths, in which numbers of individuals live together. Let us consider briefly the colonial type of sponge.

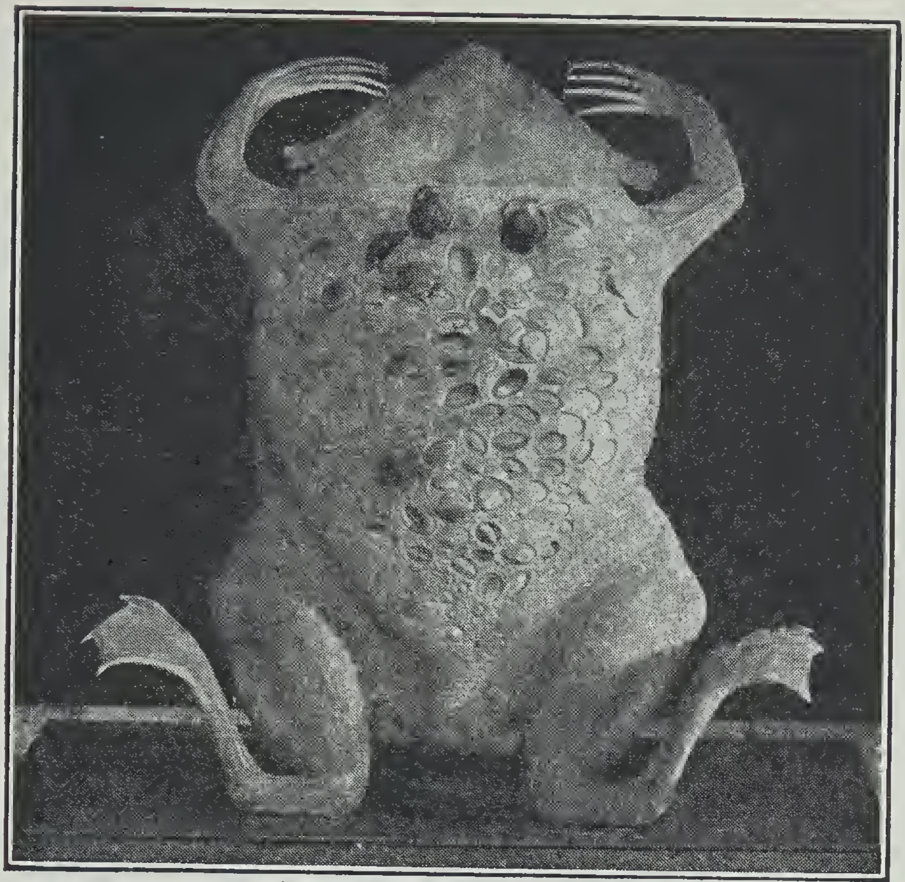
Colonial sponges. We find that a colony begins with one individual attached to the bottom in shallow water. If conditions of life are favorable this individual develops buds, and the buds remain attached to the parent. The buds grow and produce buds in turn. The result is a colony in which all individuals carry on their own life activities but are attached to each other. Such colonialism also is exhibited, in the same manner, by some species of corals.

But colonial life of this nature has its bad features; one of them is that the colony is not able to move about. The character of the bottom of the sea, where these animals live, is likely to change from time to time. Shifting sand and mud may be deposited and after a time a colony may be destroyed. Other colonies are forming meanwhile, however, in new and favorable locations.

Sexual reproduction in sponges. This formation of new colonies is possible because the sponge carries on sexual reproduction in addition to the budding process. In sexual reproduction, sex cells from the middle layer of the sponge unite to form fertilized ova. The fertilized ova develop into ciliated larvæ. The latter then break free from the parent and swim about near the surface of the water while they continue their development. After a period of growth these larvæ drop to the bottom and become attached. They become the parents of new colonies.

Oyster. An oyster, which is a much more complex animal than a sponge, is also fixed in position in the adult state and subject to destruction by shifting sand and mud. Male and female individuals are developed. The female may produce some sixteen million eggs in a season; the male produces numerous sperms. The sperms are discharged into the water, and their union with the eggs or ova in fertilization seems to be largely a matter of chance.

Development of an oyster. The fertilized ova of an oyster develop into ciliated larvæ as in the case of a sponge, and these larvæ swim about near the surface of the water for a period of time. Since great numbers of the larvæ are eaten by larger marine animals, only relatively few survive. The survivors develop tiny shells and drop to the bottom, where they become attached to solid objects, such as rocks, for the rest of their lives. This free-swimming stage in the life cycle enables members of the species to locate in new and favorable spots. The free-swimming stage in early life is a common phenomenon among marine animals that are more or less fixed in position as adults.



American Museum of Natural History, New York.

FIGURE 177. The surinam toad of South America. The eggs are carried in pouches on the back of the female. The young emerge from the pouches as toads rather than as tadpoles.

Aphids. Previously we have given some consideration to the life cycle in insects. Certain species of aphids (members of the true bug [1] group) furnish an interesting variation. In the spring of the year eggs that were laid during the preceding fall hatch to produce a generation of females. These females are able to reproduce without having their eggs fertilized by sperm.

Insects which bear their young. As a matter of fact such female aphids do not always lay eggs. Some of them bear their young; that is, reproduce viviparously. In this manner some fifteen or sixteen generations of females may be produced during the summer season. In the fall a final generation appears. In this generation both males and females are represented. The males now fertilize the females, after which the females lay fertilized eggs that are not destined to hatch until the following spring.

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[1] The "bugs" are members of one insect order, the Order Hemiptera.

Reproduction in other insects. Other interesting cases are to be observed among some insects whose eggs are laid in water. The larvæ and pupæ are aquatic, but the adult emerges from the water. Such a case is illustrated by mosquitoes, whose life cycles are discussed in another chapter. There also are cases among insects where eggs are deposited in the ground (for example, grasshoppers), or in the bark of trees (buffalo tree hoppers), or in the bodies of other animals (some parasitic flies and ichneumon flies).

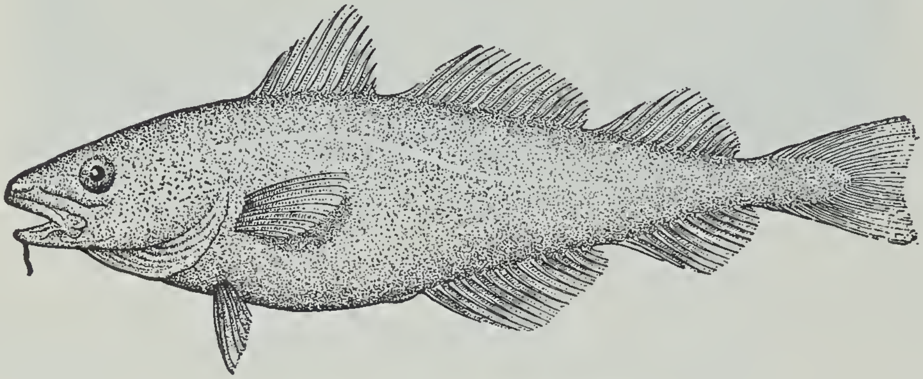


FIGURE 178. A codfish.

Codfish. Among vertebrates, various types of reproduction are developed. One type may be illustrated by the case of the codfish. The average-sized female codfish lays some two to four million eggs. The eggs contain oil globules which cause them to float at the surface where many of them are eaten by various animals. The male codfish swim among the eggs and discharge their sperms into the water. Fertilization thus is left somewhat to chance encounter of the eggs and the sperms.

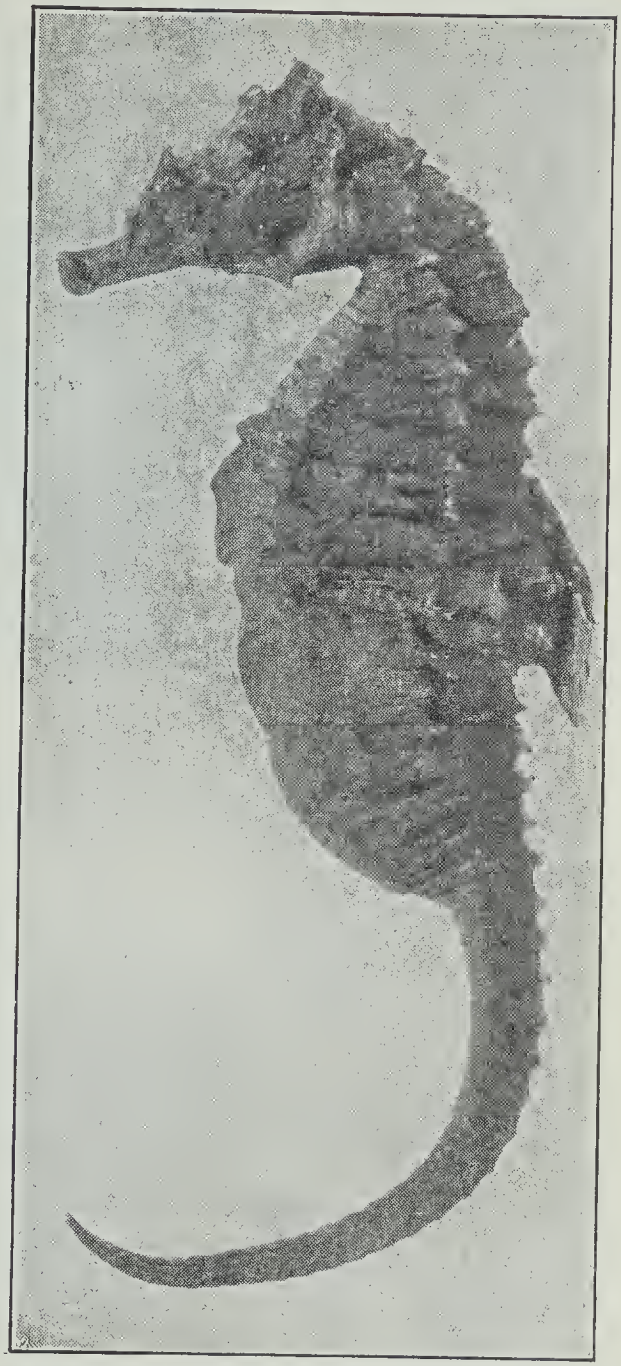
If conditions are favorable the fertilized eggs of the codfish soon hatch, and the young codfish seek the comparative safety of shallow water.

Amphibians. In studying the animal body we learned how reproduction is accomplished in the case of the leopard frog. As a general rule amphibians, although they may be air breathers as adults, must return to the water to deposit their eggs. In some cases, however, amphibians are viviparous and bear their young.

Reptiles. The eggs of reptiles, unlike those of amphibians, will develop on the land. Now not all reptiles lay eggs. For instance, garter snakes, water snakes, and water moccasins are viviparous (bear the young). On the other hand, black snakes, bull snakes, the common turtles and alligators are oviparous (lay eggs).

Birds. All birds are oviparous. Different species vary greatly as to provision for the care of young. In some cases an elaborate nest is provided; in other cases the eggs are merely laid upon some surface. In any event the eggs have been fertilized before they have been laid.

Mammals. Interestingly enough, while most mammals bear their young, the members of the lowest order[1] lay eggs. This is illustrated in the cases of the spiny anteater (Echidna) and the duckbill (Ornithorhynchus). These animals are found in the Australian region. Kangaroos and their allies also present an



American Museum of Natural History, New York.

FIGURE 179. A sea horse. In the case of this species the male carries the eggs in a brood pouch until the time of hatching.

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[1] Order Monotremata.

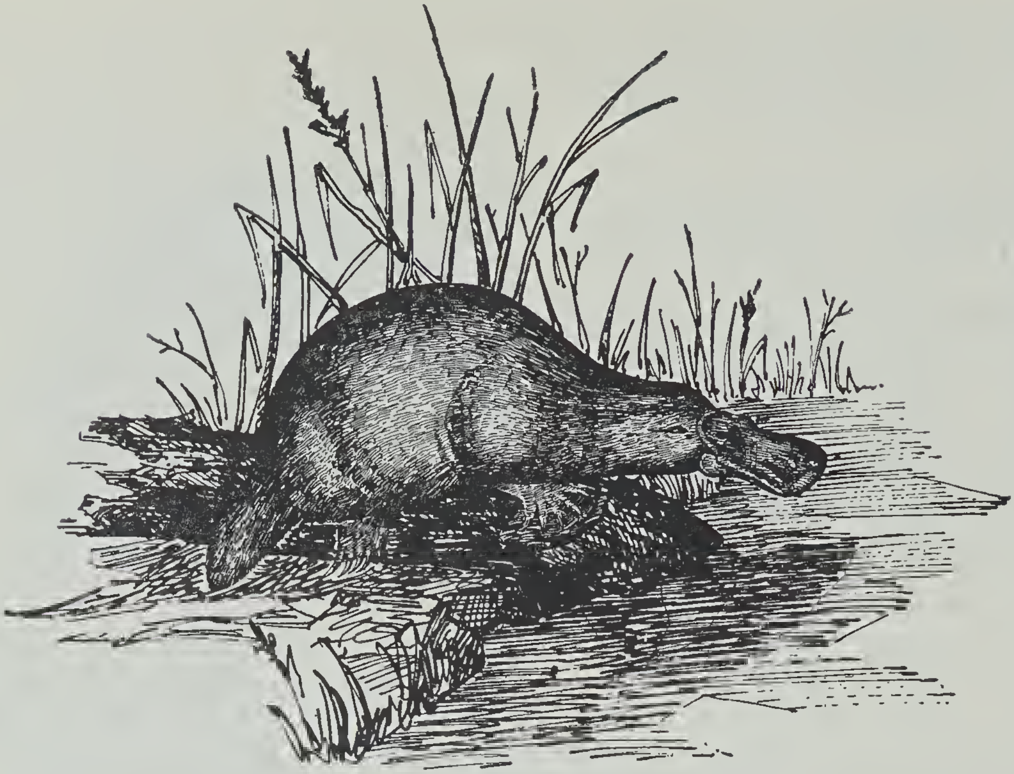


FIGURE 180. The duckbill — an egg-laying mammal.

interesting case because the young are born in such an immature condition.

With the exception of most of the foregoing types, the female mammal develops a special (internal) structure for the nourishment of the young known as the placenta. In the wall of the placenta, blood vessels of the parent come in close proximity to the blood vessels of the embryo. Although blood vessels of parent and embryo are not actually connected, materials pass back and forth between them, probably as a result of osmotic pressure. Thus the embryo receives oxygen and food from the blood of the parent. Waste passes over from the blood of the embryo to the blood of the parent.

Summary. In the foregoing discussion, we have learned that some of the simpler animals, like some of the simpler plants, reproduce by means of fission. Sexual reproduction occurs among many-celled animals (metazoa), but among the simpler types it often is supplemented by asexual methods such as budding and fission. The fertilized ovum of a complex animal undergoes a series of divisions or cleavages which result in the formation of a blastula. The latter continues to develop into a gastrula, which has two cell layers, an outer ectoderm, and an inner endoderm. Between these layers, a third layer of cells (mesoderm), now develops. Ectoderm, mesoderm, and endoderm are the "three primary germ layers." Each of these germ layers gives rise to the same specialized adult structures in most animals, although the germ layers themselves are unspecialized in early development.

The details of sexual reproduction vary among different species of animals. Some are oviparous (egg-laying), and others are viviparous (bear the young). In many mammals the early development of the young takes place within the body of the female in connection with a special structure known as the placenta.

SUGGESTED ACTIVITIES

Scientific methods

A scientist often continues experiments over long periods of time before arriving at a belief.

1. With the aid of the microscope examine demonstrations of conjugation and cell division in Paramecium, and of budding in Hydra.
2. If living specimens of Planaria dorotocephala are available in the school aquarium, devise and perform some regeneration experiments. Observe the results over a period of days.
3. Prepare models (clay), or charts, illustrating cleavage in a sea urchin. (See page 390.) Models of the blastula and gastrula stages should be included.
4. Examine slides (microscope or microprojector demonstration) which illustrate cleavage, the blastula, and the gastrula in a sea urchin or a frog. (See page 390.)
5. Investigate and report upon the life cycles of the cabbage butterfly, the codling moth, a mosquito, the Chinook salmon, the herring, a frog, a turtle, and the Virginia opossum.
6. Determine the approximate number of eggs within the body of a female fish. Obtain a fish with roe (eggs). Remove the eggs and boil them. Then weigh ten or twenty of the eggs. Now weigh the entire mass of boiled eggs and calculate the total number of eggs from the figures you have obtained.
7. Investigate reproduction in the domesticated chicken. What is

meant by "incubation"? What is the period of incubation of a hen's egg? What is the body temperature of a hen? Is this temperature maintained in an incubator? Boil a fertilized egg and locate the embryo on the surface of the yolk. Write an account of your investigation.

8. Keep some guppies (small viviparous fish) in a special aquarium. Study their habits in reproduction. Note the ratio of survival of the offspring. How frequently are young produced? Is this type cannibalistic?
9. Select the definition from column B which best describes each of the terms in column A.

A.	*B.*
Viviparous	1. lays eggs
Oviparous	2. reproduces by budding
Hermaphroditic	3. bears young
	4. both eggs and sperm formed in one individual
	5. reproduction asexual

SUMMARY OF PRINCIPLES

1. Some simple animals reproduce by asexual methods.
2. Many-celled animals reproduce by sexual methods, with the exception of certain lower forms, which may also reproduce by budding, by fission, or by regeneration.
3. After the ovum of a many-celled animal has been fertilized, it undergoes a series of cell divisions or cleavages. This results in the formation of a blastula, which consists of a single layer of cells around a hollow center.
4. The next step in development is the formation of the gastrula, which has two primary germ layers, the ectoderm and the endoderm.
5. Further development results in the formation of a third primary germ layer, lying between the other two layers. This layer is known as the mesoderm. In early development the three primary germ layers are unspecialized.
6. Each primary germ layer gives rise to the same specialized structures in the development of most species of animals.
7. Many special types of reproduction are found among the various species of animals.

GUIDE QUESTIONS

1. Name two plants and two animals which reproduce by fission.
2. Distinguish between the terms "sexual" and "asexual."

3. What is an hermaphroditic or monœcious organism?
4. Discuss cleavage, as it occurs in sea urchins. Why is this known as "equal" cleavage?
5. Describe the structures of a blastula and a gastrula.
6. Name the three primary germ layers and discuss their significance.
7. Discuss some of the features of reproduction as exhibited by sponges, oysters, aphids, and codfish.
8. What are the meanings of "oviparous" and "viviparous"? Give examples.
9. Name two snakes that are viviparous and two that are oviparous.
10. Are there any mammals which are oviparous?

BOOKS TO READ

Hegner, R. W. *College Zoology.*
Mavor, J. W. *General Biology.*
Newman, H. H. *Outlines of General Zoology.*
Woodruff, L. L. *Foundations of Biology.*

UNIT VI

VARIATION AND HEREDITY

IN OUR study of reproduction we have learned that a species cannot survive unless it has a successful means of reproduction. The mere production of offspring is not enough in itself to insure survival of the species. Some of the offspring must grow to maturity and reproduce, if the species is to be successful.

We have also learned that environment changes continually. Some of the changes are very far-reaching. When such changes occur they affect the lives of organisms. The balance in nature is disturbed, and a readjustment takes place. Some species are able to survive because they possess adaptations which are suitable for the new conditions of life. Other species may become extinct.

In the following discussion we shall learn that the members of a species are not identical in structure. Structure tends to vary in nature. What, then, is variation? How does variation affect a species? We shall learn that some variations are inherited from generation to generation. Other variations are not inherited.

We learn from the fossil record that many species have become extinct. Some of these extinct species have left descendants in the form of other species. Within modern times such species as the passenger pigeon and the Labrador duck have become extinct. New varieties of cultivated plants and domesticated animals have been developed. Hence we see that racial changes are not confined to the past — they are taking place in the modern world. Another phase of this problem is the changing distribution of species. We shall learn that the present distribution of species results from the operation of natural laws.

The study of variation leads naturally to a discussion of heredity. What is heredity? What kinds of characters may be inherited, and how is this accomplished? We shall learn that there are certain laws of heredity, such as Mendel's law. Some rules of heredity have applications to human affairs. We shall wish to know how we may profit through knowledge of hereditary laws.

CHAPTER XXV

VARIATION AND HEREDITY

Problems:

1. What changes in nature may be observed?
2. How are variation and heredity involved in natural selection?
3. Are all variations inherited?

CHANGES OCCUR IN NATURE

Changes in nature. One of the most dependable propositions concerning nature is that things change. To illustrate what is meant by this statement, let us consider the plant and animal population of a valley. Any valley will serve our purpose.

At a given moment this valley will be inhabited by certain plants and certain animals. Some of the plants will be green plants, others will be parasitic or saprophytic plants. Some of the animals will be flesh eaters, others will be plant eaters, and still others will eat both flesh and plant materials. But at a given moment, there will be a certain number of species present, and each species will be represented by a certain number of individuals. Furthermore, there will be an average size, weight, color, etc., for each species.

Five minutes later conditions in this valley will have changed. The nature of the changes will vary somewhat, depending upon the season of the year and other factors, but there will be many changes. Some of the plants that were flourishing five minutes before will have been eaten by some of the animals. Other plants may have begun to sprout from seeds. Some of the animals may have been killed by others, and young animals have been produced meanwhile. Disease will have taken its toll. The last individual of a given species may have died, causing that species to become extinct. Certain plants and animals have grown, or have lost weight. Seeds from certain plants may have entered the valley, borne by the wind. Animals from other regions may have entered the valley, and animals originally in the valley may have departed.

The foregoing changes are only some of the many changes that may take place within a five-minute interval. At the end of this five-minute period, the number of species within the valley may have changed. In the case of any single species, the average size, weight, color, etc., of the species will probably have changed. The number of individuals will have changed in the case of many species.

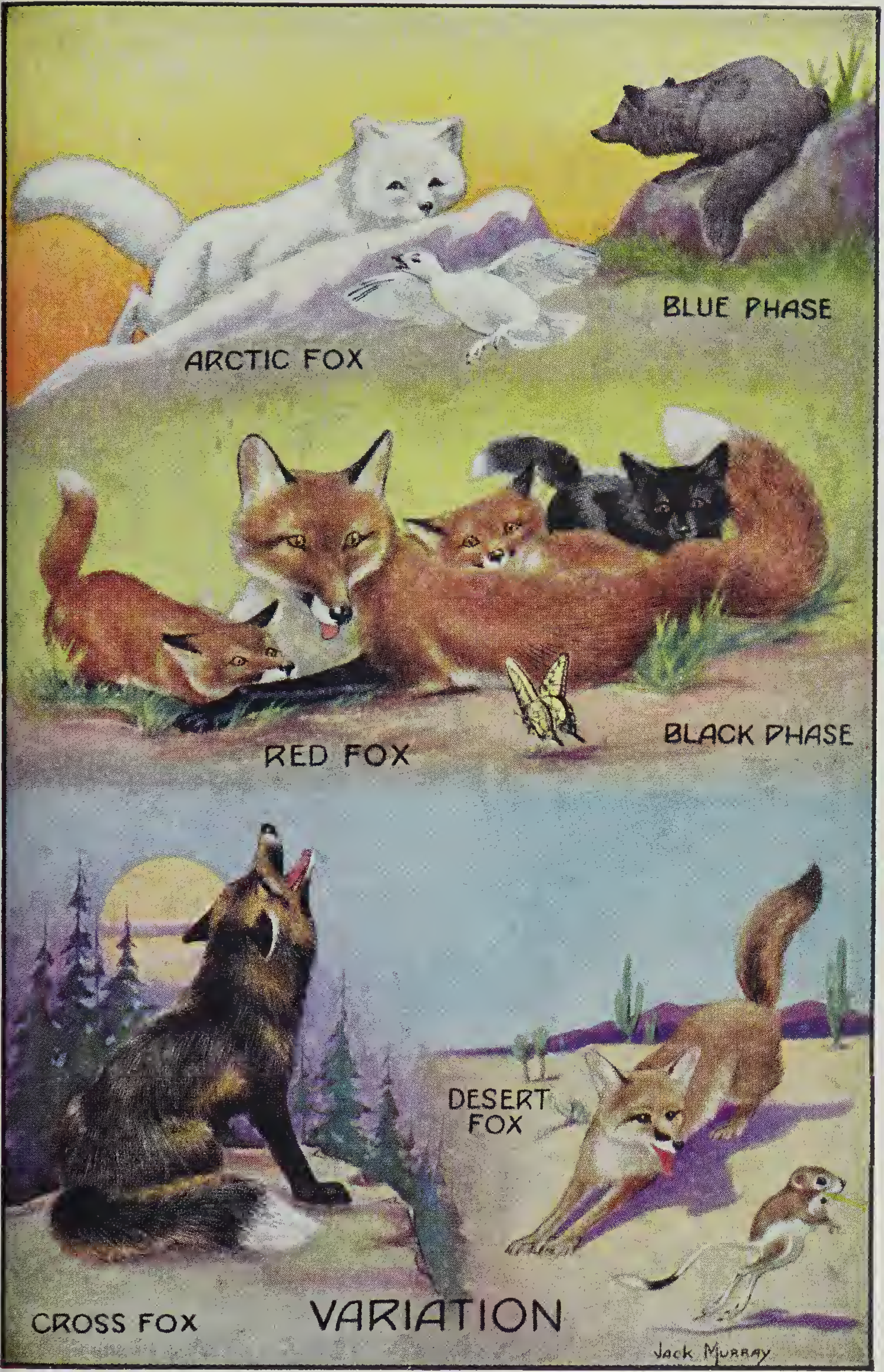
Racial changes. We come to the conclusion that situations in nature are likely to be in a state of constant change. Often the changes are slight and pass unnoticed. Sometimes, however, they are marked and important. Man has long been interested in variation and racial changes. By racial changes we mean changes in species or varieties of either plants or animals.

OUR KNOWLEDGE OF VARIATION HAS BEEN ACCUMULATED SINCE THE TIME OF ARISTOTLE

Aristotle. Aristotle (384–322 B.C.) was a Greek philosopher. He had many interests, and among them an interest in living things. He attempted to classify the plants and animals with which he was familiar. He stated that there was an "intelligent desire" in nature and that events moved in cycles.

Lucretius. Lucretius (99–55 B.C.) indicated a belief in the struggle for existence and the survival of the fittest among organisms. Along with this he suggested the probability that racial changes did occur. Then a long period of time elapsed before any new advances along such lines of thought were made. The Middle Ages intervened, and very little biological knowledge came to light during these centuries.

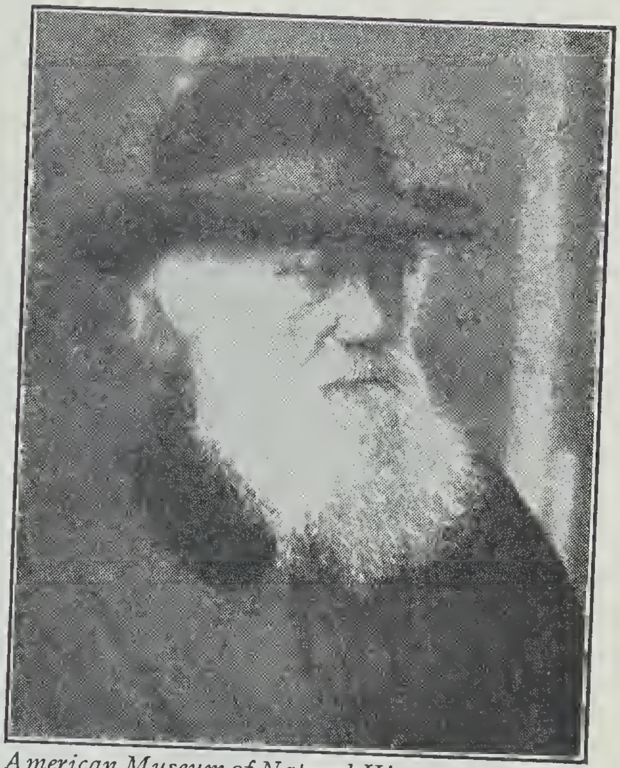
Middle Ages. Throughout the Middle Ages there was a marked tendency to decide questions concerning biological matters by reference to the writings of Aristotle and other men who lived before the fall of the Roman Empire. Apparently, it was not commonly the practice to study plants and animals in seeking answers to these questions. Scientific methods were not in common use.


ARCTIC FOX
BLUE PHASE
RED FOX
BLACK PHASE
DESERT FOX
CROSS FOX
Jack Murray

VARIATION

Buffon. Buffon (1707–1788) was a Frenchman who exhibited considerable interest in the problems of racial changes. He attempted to explain how and why they might occur. In so doing, he recognized such forces as individual variation, heredity, and the struggle for existence. Buffon's work was speculative, however. He wrote his opinions, but he had little evidence or data to support these opinions.

Lamarck. Jean Baptiste Lamarck (1744–1829) was another Frenchman who devised a rather ingenious explanation for racial changes. His theory was based upon the belief that acquired characteristics are inherited. An acquired characteristic would be something developed through contact with the environment — a change which first affected the general cells of the body rather than the sex cells. Lamarck's views were opposed by Georges Cuvier, another French scientist of his day. The great bulk of experimental evidence now available strongly indicates that Lamarck was wrong in assuming that acquired characteristics are inheritable.



American Museum of Natural History, New York.

FIGURE 181. Charles Darwin was born in England in 1809, and died in 1882. He is probably best known because of his theory of natural selection. However, he studied many other phases of biology, such as plants and animals under cultivation and domestication, the biology of barnacles and corals, the behavior of earthworms, and the pollination of flowers.

Darwin and Wallace. Charles Darwin (1809–1882) developed the theory of natural selection in another attempt to explain racial changes. Alfred Russel Wallace (1823–1913) had reached about the same conclusions at the same time, although his work was quite independent of

Darwin's studies. Wallace became an authority on geographical distribution, while Darwin is best known for his theory of natural selection.

Natural selection. In analyzing the theory of natural selection we may recognize three main points, which are as follows:

1. Variation is a common and well-known phenomenon in nature.
2. Taking organisms as a whole, more offspring are produced than can possibly survive.
3. Heredity is a recognized phenomenon in nature.

Variation. Variation is the tendency of the offspring to depart from the parental type. It is also used in referring to the fact that members of any species are not identical in structure. We look at a group of cottontail rabbits and they appear very similar to each other. If we make comparative studies of their measurements, weights, and similar factors, however, they show a considerable range of variation. Or take a group of trees of the same species that are identical in age. Each tree will not have the same number of branches or leaves, or rootlets. In fact, we may find considerable differences in a group of any size. Some of these are new variations, others have been inherited from preceding generations.

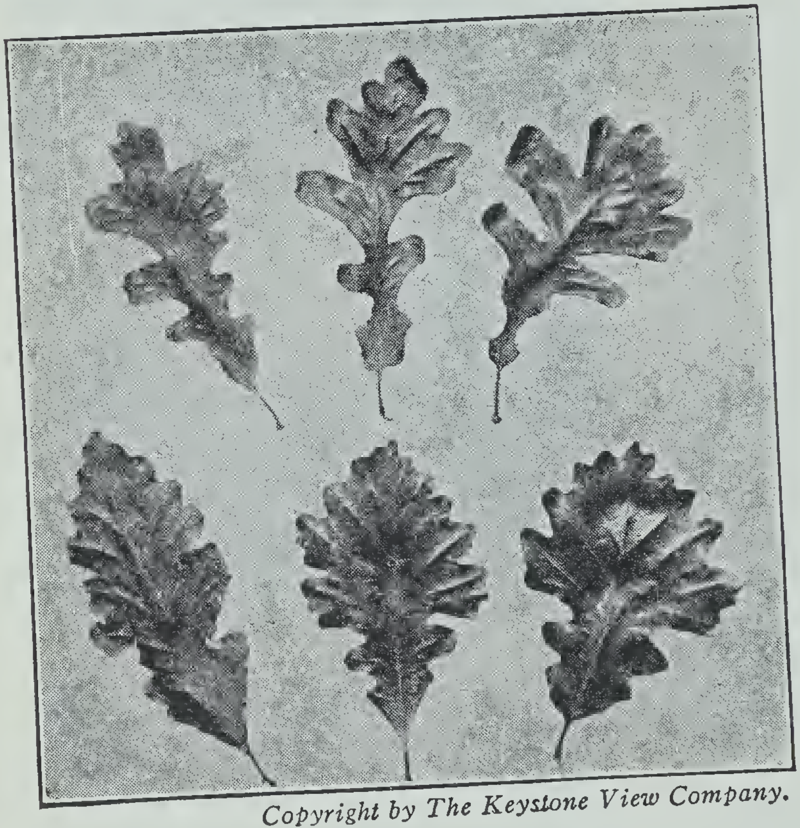


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FIGURE 182. Variation in the leaves of one species of plant.

The average type. Every species has a theoretical average type, and the individuals that make up the species vary more or less around this average. Most of the variations are small, some are large, and a few are extreme.

Ratio of increase. When we study the rate of reproduction in many species, we discover that more individuals are produced than can possibly survive. If all seeds germinated and produced mature plants, if all eggs hatched to produce organisms that grew to maturity, and if all animals born were to grow to maturity, the world would soon be overpopulated.

The death rate. Another factor that enters into the situation is the rather high death rate in nature. Many seeds do not develop, many eggs do not hatch, and many organisms are destroyed early in their lives. If this were not true the result would soon be serious overcrowding.

For instance, let us consider the case of some fish that matures in one season and produces a large number of eggs. We may assume that the average number of eggs is 8,000,000 for the species in question, and that half of these eggs are destined to produce females. Suppose further that no individual of this species dies for a period of two years, and that there is plenty of food and water available. Then if we start with a single pair of fish, this species would number 32,000,016,000,002 individuals at the end of the second year. Obviously, this increase could not continue at its full potential rate for many years even in the case of one such species.

The answer to the above situation is that while many fishes and other animals produce large numbers of eggs, probably only a small percentage of the eggs hatch. Still fewer of the young produced will live to maturity.

Heredity. Heredity involves the tendency on the part of the young to resemble their parents. It also may be responsible for the fact that young differ from their parents to a greater or lesser degree. Our modern studies of heredity show that many structures in many species, both plants and animals, are inherited from generation to generation.

Survival of the fittest. The theory of natural selection holds that since many organisms must be eliminated for every one that survives, and that since there is considerable variation among the individuals of a species, a "survival of the fittest" will take place. "Fitness" would vary, depending upon the conditions of the environment. The individuals best adapted to the conditions of the environment would be the "fittest." These individuals, in the long run, would survive. The less well-adapted individuals would be eliminated. Then, through the agency of heredity, those structures and qualities which made survival possible, would be transmitted to future generations. In other words, the structures and qualities that made for fitness would come to be, or would remain incorporated in the race.

Adaptation of the species. Thus there would be a definite tendency to keep the race adjusted or adapted to the changing environment. The unfit individuals would be eliminated to the benefit of future generations. There would be a tendency toward race improvement, if we define race improvement as the tendency of the species to become adapted to the conditions under which it lives. In a word, natural selection is selection through the survival of the fittest.

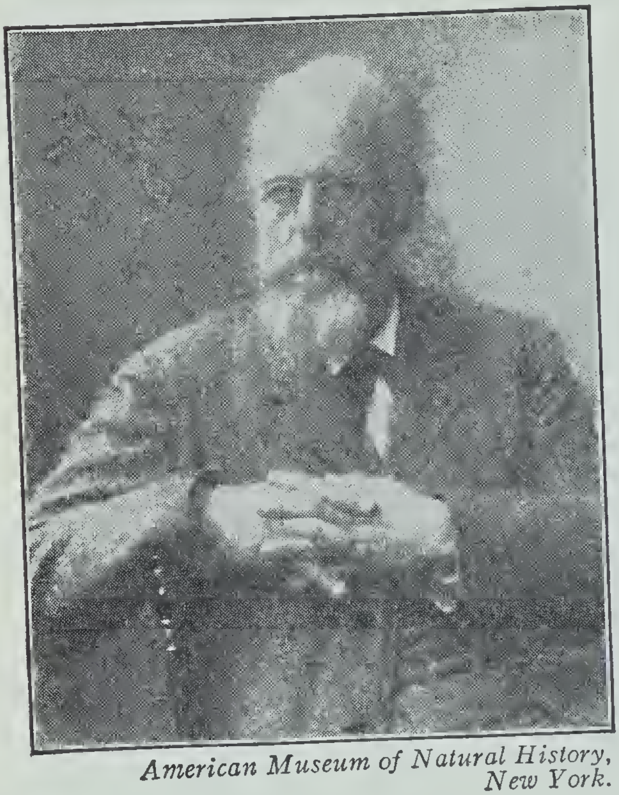

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FIGURE 183. August Henry Weismann (1834–1914) was a German scientist who made very important contributions to our knowledge of heredity and racial change. He made use of the experimental method in studying the inheritance of various characters.

NOT ALL VARIATIONS ARE INHERITED

Weismann. August Weismann (1834–1914) was a German who made very significant additions to our knowledge of variation and heredity during the latter part of the nineteenth century. He performed a classic experiment to test whether or not acquired characteristics could be inherited. He cut off the tails of mice for twenty-two generations. The loss of the tails would represent an acquired characteristic of the mutilation type. In all, 1592 mice had their tails removed at birth. The tails of a final generation of mice were allowed to grow undisturbed, and Weismann found that these tails attained normal length.

Kinds of variation. Weismann defined acquired characteristics as those which have their origins in the somatoplasm — in other words, characteristics which have their origins in any cells of the body *except* the sex cells. Germinal characteristics are those which have their origin in the sex cells (germ-plasm). Congenital characteristics are present at birth, and may include both acquired and germinal characteristics.

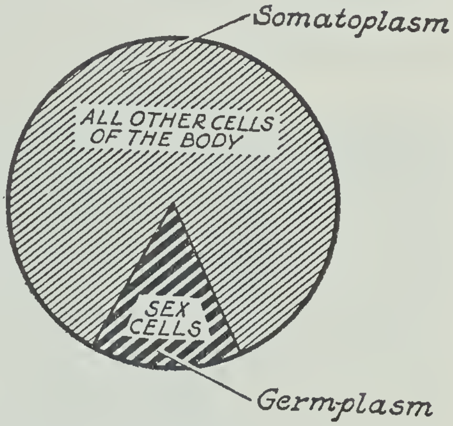


FIGURE 184. Germ-plasm and somatoplasm. In this diagram, the area within the circle represents the individual.

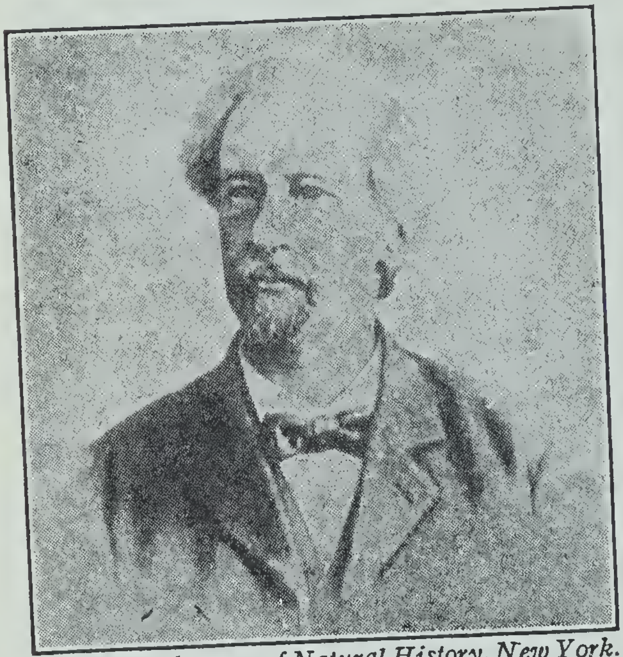
Inheritable variations. Weismann denied the inheritance of acquired characteristics. For one thing he said that there was no known means whereby a change in the somatoplasm could become transferred to the sex cells. He further stated that the evidence that any such transfer did occur was inconclusive. And finally, he stated in substance that the inheritance of germinal characteristics was quite sufficient to account for all of the known facts of heredity.

ONLY INHERITABLE VARIATIONS AFFECT THE RACE

Weismann and natural selection. Naturally, the investigations conducted by Weismann had an important bearing upon the theory of natural selection. For the variations in the original theory included both germinal characteristics and acquired characteristics. If acquired characteristics were not inheritable, they could not produce racial changes, but would die with the individual. Although a believer in natural selection, Weismann recognized this fact. Weismann wished to establish natural selection upon a surer scientific basis. He felt that the inheritance of germinal characteristics was sufficient to account for the phenomena of racial change.

We find that the modern concept of natural selection is somewhat different from the original theory. This is largely due to the influence of Weismann, who is said to have founded the neo-Darwinian school of thought. For obviously, only inheritable variations can have a permanent effect upon the species. If a variation is noninheritable, it affects only the individual.

DeVries and the mutation theory. Hugo DeVries, a Dutchman, published his "mutation theory" at the beginning of the twentieth century. According to DeVries, mutations were *large* inheritable variations. He had studied the evening primrose, which grew in abundance in parts of Holland. He had observed what he believed to be the origin of new species or varieties, as a result of *large* variations. He suggested that a species might continue for many generations without any great change, and then enter a period during which it would produce a number of new types by mutation.



American Museum of Natural History, New York.

FIGURE 185. Hugo DeVries, a Dutch biologist, formulated the "mutation theory." Although it has been questioned that DeVries observed mutation occurring in Lamarck's evening primrose, numerous cases of mutation are now known to science.

DeVries was of the opinion that this had occurred in the case of his evening primroses. He also suggested that natural selection would determine which of the new varieties produced would be successful and which varieties would be unfitted to the environment. But he did not agree entirely with the concept that the accumulation of relatively small variations was the important factor in producing racial changes. He inclined more to the belief that only large inheritable variations (mutations) were of importance in producing racial changes.

DeVries's work has been assailed upon the ground that his evening primroses really were hybrids. That is, they represented crosses or mixtures of several different varieties of the evening primrose. If such were the case, he might have observed merely the reappearance of certain ancestral types which were not new. It also is worthy of note that the word "mutation" has changed in meaning since the beginning of the twentieth century. It now means any inheritable variation.

Mutations. Nevertheless, there have been a number of recorded racial changes in which new varieties have appeared as the result of marked inheritable changes, or mutations, as DeVries used the term. Such cases have occurred both among plants and among animals.

Ancon sheep. For instance, in 1791, a lamb having an unusually long back and short, bent legs was born on the farm of a Massachusetts farmer. The farmer recognized that sheep of this build might be desirable because they would have difficulty in jumping fences of any height. And so this lamb became the ancestor of the Ancon variety of sheep.

Polled Herefords. At Atchison, Kansas, in 1889, a hornless calf was born, which became the ancestor of polled Hereford cattle. At the present time we have a number of hornless breeds of cattle. It is no longer necessary to dehorn herds of cattle to prevent them from injuring each other or doing damage to other animals and objects with their horns.

Plant mutations. The double petunia appeared at Lyons, France, in 1885. Another plant, the fringed celandine, appeared at Heidelberg, Germany, in 1590. The Shirley poppy first appeared in England in 1882. More recently a red variety of the ordinarily yellow sunflower has appeared in this country. Many other cases of mutations, both large and small, are on record. For instance, numerous varieties of many species of cultivated plants and domesticated animals have had their origins in mutations.

DeVries and natural selection. It should be observed that

DeVries's mutation theory has a definite relationship to the theory of natural selection. DeVries regarded his mutations as the variations that are significant in producing racial changes. At the same time, he does not deny the theory of natural selection. He suggests that natural selection will eliminate new varieties of organisms which are not fitted to their environment. Darwin was aware that there were such things as "sports" or large variations in nature, but he did not focus attention upon them.

Summary. The subject of variation, and its biological effects, has been of interest to students of plant and animal life since the day of Aristotle. Various theories have been advanced in an effort to explain variation and racial change. One of these is the theory of natural selection. Certain points in this theory have been criticized in the light of newer knowledge. We find, however, that the central idea of the struggle for existence and the survival of the fittest has remained more or less intact. Weismann's studies had a profound influence in tending to eliminate acquired characteristics from consideration. To a lesser degree, DeVries has modified our concept of racial changes by centering attention upon *large* germinal variations. So we find that the modern concept of natural selection is not identical with the original concept. This is to be expected, since much new knowledge has been revealed. One modern view of natural selection holds that species become adapted to changing environment through a survival of the fittest. The fittest are those which are best adapted to survive in the existing environment. Only germinal variations, however, are of consequence in changing the race. This is because such variations may be inherited by future generations. The degree of change in a race is determined by the degree of variation, and the strictness of the selection.

SUGGESTED ACTIVITIES

Scientific methods

A scientist prepares for his own investigations by reading about the experiments of others which have some bearing upon the problem.

1. Devise and describe an experiment of your own (you need not perform it) for the purpose of gathering some evidence about the inheritance of acquired characteristics.
2. After reference to *From the Greeks to Darwin*, by Osborn, write an estimate of the contribution of Goethe to an understanding of the descent of plants and animals.
3. Prepare an exhibit which illustrates the principle of variation. Select some species (plants or insects will probably be easier to obtain) and gather a large number of specimens — all of the same species. Study the materials. Are there any two that are exactly alike? Mount the specimens upon a display board for the inspection of your class.
4. Make collections of leaves, seeds, fruits, or flowers — in each case representing a single species. Study them for evidences of variation.
5. Counting the thumb as the first finger, compare lengths of the second and fourth fingers among members of the class. In how many cases is the second finger longer than the fourth finger? In how many cases is the reverse true? In how many cases are the second and fourth fingers of about equal length? Compare the two hands of the same person with respect to these characteristics.
6. After consulting the reading references at the end of this chapter, prepare reports upon the experiments of Weismann and DeVries.

SUMMARY OF PRINCIPLES

1. Changes in the environment occur constantly; these changes affect the well-being of plants and animals.
2. Knowledge of variation and heredity has been accumulating since the time of Aristotle.
3. The theory of natural selection attempts to explain racial change.
4. Every organism varies somewhat from its parents and from every other organism. This is a simple statement of the principle of variation.
5. Many organisms *tend* to increase in number at a rapid rate. Such a rate of increase would produce more of many species than could possibly survive.
6. The actual rate of increase of any species is usually much less than the potential rate on account of a high death rate, especially during early life.
7. "Survival of the fittest" refers to the theory that since some organisms must die and others live, the best fitted (adapted) are most likely to survive.
8. Some variations are inheritable and others are not.

9. DeVries gave the name "mutations" to large variations which were inheritable.
10. Studies made since the time of Charles Darwin tend to modify our concept of natural selection.

GUIDE QUESTIONS

1. Mention four changes in the life of a valley or other natural region, that may occur in the space of five minutes, under normal conditions.
2. What is meant by racial changes?
3. Who was Aristotle and what is his relationship to natural science?
4. To whom is credited the earliest statement of belief in "survival of the fittest"?
5. What is meant by "acquired characteristics"? Give an example.
6. Who explained racial changes by the inheritance of acquired characteristics? Who opposed him in his own generation?
7. Why were Darwin's conclusions more "scientific" than those of his predecessors?
8. Discuss three major premises of the theory of natural selection.
9. Do offspring usually resemble the parent in most respects or only in a few qualities? Illustrate.
10. What prevents overpopulation of the world?
11. How is the principle of "variation" related to "survival"?
12. What biologist first made experiments to disprove the inheritability of acquired characteristics? Describe one experiment.
13. What is the "mutation" theory? Who originated this theory?
14. Give two examples of notable, useful mutations.
15. What is meant by "germ-plasm" and "somatoplasm"?

BOOKS TO READ

Holmes, S. J. *Introduction to General Biology.*
Lull, R. S. *The Ways of Life.*
Newman, H. H. (ed.) *Nature of the World and of Man.*
Osborn, H. F. *From the Greeks to Darwin.*
Shull, A. F. *Principles of Animal Biology.*
Walter, H. E. *Genetics.*

CHAPTER XXVI

CHANGES IN RACES

Problems:

1. To what extent do organisms resemble one another?
2. What do we learn from the fossil record?
3. Is the geographical distribution of organisms the result of the operation of natural laws?
4. What do we learn from the study of development?

CHANGES HAVE BEEN OBSERVED IN CERTAIN MODERN SPECIES

Foreword. In the preceding chapter we have studied some of the changes in species that are matters of historical record. We have noted the appearance of Ancon sheep, polled Hereford cattle, red sunflowers and other new types. To this list we might add the many varieties of dogs, chickens, pigeons, and other domesticated animals; also various types of cultivated plants. These varieties are the result of variation and selective breeding.

Domesticated varieties. It is true that such cases refer to domesticated animals and cultivated or semicultivated plants. But of course these are the types with which we are most familiar, and concerning which we have the best records. It has long been recognized that variations in domesticated animals and cultivated plants are more likely to persist than are some variations in a state of nature. Many of these variations would probably be disadvantageous to their possessors were the latter not under the protection of man.

Species of plants and animals, therefore, have been known to vary within historical time. There are several other lines of study which furnish evidence with regard to variation and racial changes.

THE STRUCTURES OF ORGANISMS SHOW BASIC RESEMBLANCES

In our previous studies we have learned that protoplasm is the basic living substance. It is common to all organisms. Protoplasm is the living substance of all plants, and it also is the living substance of all animals.

Similarly, we have learned that the cell is the unit of structure (cell principle). All plants are composed of cells, and all animals are composed of cells. The living substance of such cells is protoplasm.

Similarities of plants and animals. In other words, the unit structures of both plants and animals are the cells which contain the living substance protoplasm. In the bodies of the more complex plants and animals some cells are highly specialized in form and function. But basically, they are cells, composed of protoplasm. This similarity of unit structure, found in all organisms, suggests basic relationship of plants and animals.

Borderline organisms. We have learned, as a matter of fact, that some of the simpler organisms exhibit both plant and animal characteristics. There are a number of "borderline" types which are difficult to classify definitely, either as plants or as animals. This condition of affairs serves to emphasize the fact that there is a basic or fundamental resemblance among all organisms.

Classification expresses relationships. Plants and animals have been classified upon the basis of structure. A species of animal or plant consists of a group of individuals which are not identical in structure, but are approximately alike. In fact, we may divide a species into subspecies. The members of a subspecies are more nearly alike than are the members of a species.

In arranging the classification scale of animals and plants, it has been the custom to place the groups that contain the simplest types at the bottom of the scale. Groups showing greater complexity of structure come next in order. Thus we find that groups containing the most highly specialized types are placed at the tops of the respective classification series (plants or animals).

Plant classification. The following list represents a simplified version of the classification of plants. Only the larger groupings are represented in this list:

Division Spermatophyta: Seed plants.
  Series Angiospermæ: "Common" flowering plants.
    Class Dicotyledoneæ: Roses, pinks, daisies, buttercups, radishes, sweet peas, pumpkins, melons, lettuce, cacti, beans, elms, willows, etc.
    Class Monocotyledoneæ: Orchids, lilies, palms, sedges, grasses, cattails, etc.
  Series Gymnospermæ: Conifers and cycads.
Division Pteridophyta: Ferns, and related types.
    Class Lycopodineæ: Lycopods.
    Class Equisetineæ: Horsetails.
    Class Filicineæ: Ferns.
Division Bryophyta: Mosses and liverworts.
    Class Musci: Mosses.
    Class Hepaticæ: Liverworts.
Division Thallophyta: Fungi and algæ.
  Series Fungi.
    Class Basidiomycetes: Mushrooms, rusts, and smuts.
    Class Ascomycetes: Yeasts, morels, and mildews.
    Class Phycomycetes: Molds.
    Class Schizomycetes: Bacteria.[1]
  Series Algæ.
    Class Rhodophyceæ: Red algæ.
    Class Phaeophyceæ: Brown algæ.
    Class Chlorophyceæ: Green algæ.
    Class Cyanophyceæ: Blue-green algæ.

Simple and complex plants. In examining the foregoing classification, we find that the algæ have been placed at the bottom of the classification scale. They represent the plants which are among the simplest or most generalized in structure. On the other hand, the seed plants are regarded as being the "highest" or most complex plants. They represent the most recent structural developments among plants. Consequently, they are placed at the top of the classification scale.

There is considerable difference in structure between an alga and a seed plant. One is a relatively simple organism, the other is a relatively complex organism. But if we compare a green alga and a brown alga we find that they are not vastly different from each other. Then if we compare a brown alga with a red alga we find again that the differences are not very great.

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[1] Not always classified as fungi.

In other words, if we start with the plants at the bottom of the scale, and pass upward from group to group, we find a more or less gradual increase in complexity. The higher plants are quite different in appearance from the lower plants, but there are many intermediate types.

Animal classification. We shall now consider a classification of the major animal groups, arranged in the same manner, with the simpler types at the bottom of the scale and the more complex types at the top:

- Phylum Chordata.
  - Subphylum Vertebrata.
    - Class Mammalia: Mammals.
    - Class Aves: Birds.
    - Class Reptilia: Reptiles.
    - Class Amphibia: Amphibians (frog).
    - Class Pisces: Bony fishes.
    - Class Elasmobranchii: Sharks and rays.
    - Class Cyclostomata: Lampreys and hags.
  - Subphylum Cephalochorda: (amphioxus).
- Phylum Arthropoda.
    - Class Arachnida: Spiders, scorpions, mites.
    - Class Insecta: Insects.
    - Class Diplopoda: Millepedes.
    - Class Chilopoda: Centipedes.
    - Class Crustacea: Lobsters, crayfish, crabs.
- Phylum Mollusca.
    - Class Cephalopoda: Squid and octopods.
    - Class Pelecypoda: Clams, mussels, oysters.
    - Class Scaphopoda: "Elephant tusk" shells.
    - Class Gastropoda: Snails.
    - Class Amphineura: Chitons.
- Phylum Annelida.
    - Class Hirudinea: Leeches.
    - Class Chaetopoda: Earthworms.
- Phylum Echinodermata.
    - Class Crinoidea: Crinoids.
    - Class Holothuroidea: Sea cucumbers.
    - Class Echinoidea: Sea urchins.

- Class Ophiuroidea: Brittle stars.
- Class Asteroidea: Starfishes.

Phylum Trochelminthes: Rotifers.
Phylum Nemathelminthes: Roundworms.
Phylum Platyhelminthes: Flatworms.
    Class Cestoda: Tapeworms.
    Class Trematoda: Flukes.
    Class Turbellaria: (Planaria).
Phylum Cœlenterata.
    Class Anthozoa: Corals and sea anemones.
    Class Scyphozoa: Jellyfishes.
    Class Hydrozoa: Hydroids, small jellyfishes and stony corals. (Hydra).
Phylum Porifera: Sponges.
Phylum Protozoa.
    Class Infusoria: (Paramecium).
    Class Sporozoa: (Malaria parasite).
    Class Mastigophora.
    Class Sarcodina: (Amœba).

When we examine the foregoing classification of animals we find once more that the groups represent a more or less gradual increase in complexity,[1] beginning with the protozoa and ending with the specialized chordates.

A protozoan like Amœba is very much simpler in structure than a chordate (member of the Phylum Chordata), such as the dog. But these two types are widely separated in the classification scale. There are many intermediate types which exhibit the gradual increase in complexity.

Finally, let us consider two more closely related groups, such as the amphibians and the reptiles. When we study their structures we find that these types are similar. To be sure, reptiles have scales and plates, and modern amphibians do not. There also are some other structural differences. For the most part, however, amphibians and reptiles are similar in structure. The reptiles are a "higher" or more specialized type of chordate. They give every evidence, however, of having been developed from amphibianlike ancestors.

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[1] It should not be assumed that any one group has descended from the group placed below it in the classification series.

THE FOSSIL RECORD INFORMS US OF CHANGES THAT HAVE OCCURRED IN THE PAST

Prehistoric plants and animals. The life of prehistoric times has been preserved for us in the form of fossils. We have learned that these fossils represent the harder parts, such as the bones and shells of organisms, and that the shallow sea is a favorable locality for their formation. In such situations, the fossils become preserved in layers of rock. Some of these layers of rock have become elevated above the surface of the sea. Man has been able to study the fossils that they contain. Thus man finds it possible to study the succession of animal and plant forms in the region represented by the deposits. He is able to read the history of past life upon the earth.

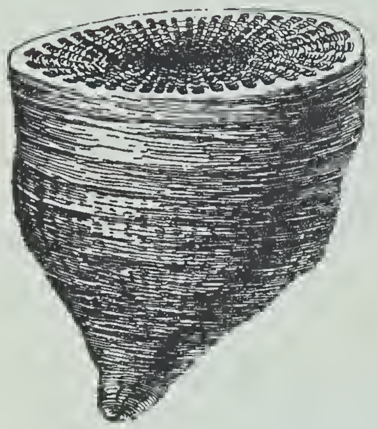


FIGURE 186. A fossil species of coral.

The table on page 419 shows the major divisions and subdivisions of geological time, with notations on the types of animal and plant life that lived during the different periods.

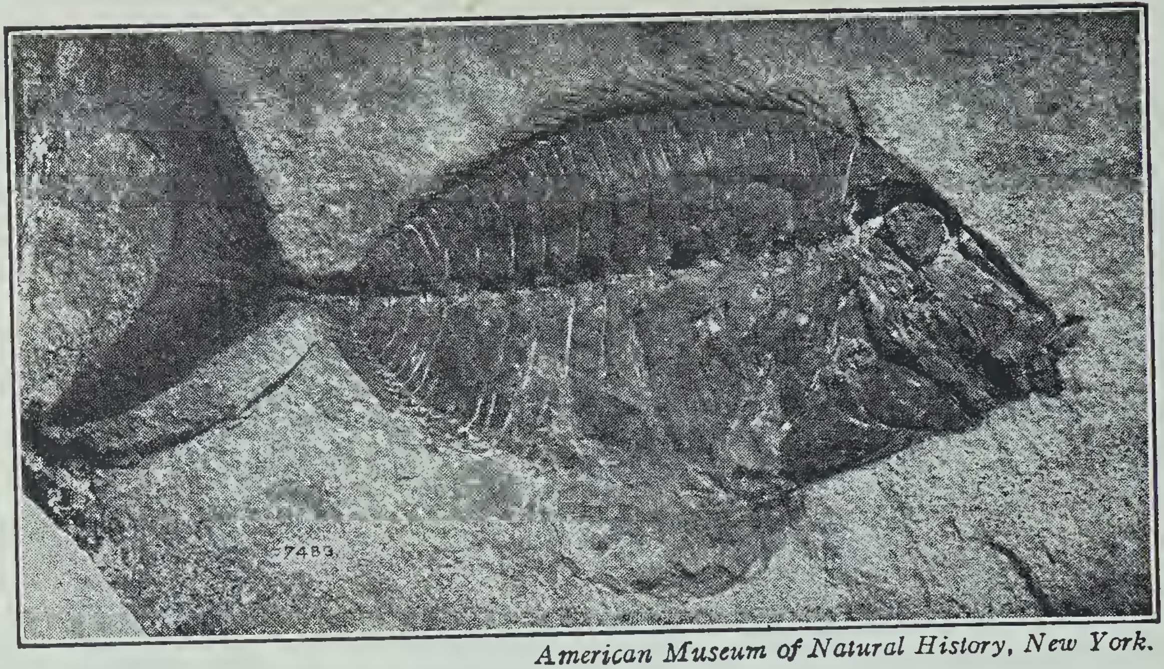
The Archeozoic and Proterozoic Eras were of very long duration. Some of the rocks that represent the Proterozoic Era contain a few fossils. No fossils are found in Archeozoic rocks, but life in some form may have existed at this remote time. Both Archeozoic and Proterozoic rocks have been changed greatly by pressure; consequently we would not expect them to contain many good fossils.

Paleozoic life. But the rocks of the Paleozoic Era abound in fossils. The Cambrian, Ordovician, and Silurian Periods were characterized by the dominance of invertebrates and the simpler plants. All animals appear to have been aquatic. Protozoa, corals, echinoderms, brachiopods, mollusks, and trilobites were represented. The trilobites were members of the Phylum Arthropoda. They were a dominant form of life in the early part of the Paleozoic Era, but the entire race has become extinct. In fact, most of the species of invertebrates whose fossil remains are found in the Paleozoic rocks have long since become extinct.

TABLE VI. DIVISIONS OF GEOLOGICAL TIME

ERA	PERIOD	ORIGIN OF DIFFERENT TYPES	DOMINANT LIFE
CENOZOIC	Quaternary		Age of Man
	Tertiary		Age of Mammals
MESOZOIC	Cretaceous		
	Comanchean	Rise of flowering plants	
	Jurassic	First fossil birds	Age of Reptiles
	Triassic	First fossil mammals	
PALEOZOIC	Permian	Rise of reptiles and insects	Age of Amphibians
	Pennsylvanian		
	Mississippian		
	Devonian	Rise of amphibians and land floras First gymnosperms and ferns	Age of Fishes
	Silurian	First true fish	
	Ordovician	First fishlike animals	
	Cambrian	Dominance of trilobites Most invertebrate groups represented	Age of Invertebrates
PROTEROZOIC		Primitive invertebrate life and perhaps algæ (?)	Unknown life
ARCHEOZOIC			Life (?)

However, many of them have left descendants in the form of other species, which have lived on into the present era. For instance, there still are living protozoa, corals, echinoderms, brachiopods, and mollusks. But the modern species are different from those that flourished during the Paleozoic Era.



American Museum of Natural History, New York.

FIGURE 187. A fossil fish. What conditions are favorable to the formation of fossils? Why are fossils of importance to science?

Age of Fishes. The Devonian Period (Paleozoic Era) is called the Age of Fishes. Some fishlike animals had appeared as early as the Ordovician Period, but the group reached the climax of its development during the Devonian. This was probably due to the fact that during Devonian time shallow seas were very extensive. Shallow seas would be likely to favor the expansion of the fish group. At the same time, land plants were undergoing their first great development.

Toward the close of the Devonian, the shallow seas became much reduced in extent. Many of the areas that had been shallow sea became land or swamps. And the first amphibian fossils now appear in the rocks. These early amphibians were similar to certain of the fishes, which probably were their ancestors. Widespread swamps would not favor the development of fishes, but would be ideal for amphibians.

Age of Amphibians. We find that amphibians were the dominant type of animal life during the Mississippian and Pennsylvanian Periods. Land floras also were well-developed. Lycopods and horsetails were common among the plants. Their fossil remains are found in the coal deposits which were laid down in the swamps during Mississippian and Pennsylvanian times. With the development of forests and land floras in general during the Pennsylvanian, came the expansion of the insect group.

Both lycopods and horsetails have persisted to the present day, although the modern species are not like the giant species of the Paleozoic, and are much less common. The amphibian group is represented in the modern world. But again, the species that lived during the Paleozoic have become extinct and have been replaced by some new species that have descended from them. Insects are common today, but modern species are not identical with the species that existed during the Pennsylvanian Period.

During the Permian Period conditions of life began to change. The climate, which had been mild and moist throughout most of the Paleozoic Era, became cold and arid. Many of the species that had flourished in the Pennsylvanian swamps became extinct or were greatly reduced in numbers, probably because they were unable to adapt themselves to the changing conditions.

Age of Reptiles. Some primitive reptilian forms had been developed from the amphibian stock during the Pennsylvanian Period. These early reptiles survived the hardships of the Permian Period and became the ancestors of the great reptile group which flourished during the Mesozoic Era. For in the Mesozoic Era the climate again became mild and moist, and apparently was favorable to the well-being of cold-blooded animals and tropical plants. The great rise of flowering plants occurred in the latter part of this era.

The Mesozoic Era is well named the Age of Reptiles. The reptile group expanded enormously both in the number of species and in the number of individuals. Ichthyosaurs were aquatic reptiles with fishlike bodies. Plesiosaurs also were aquatic reptiles. Pterodactyls were reptiles which developed wings and probably were able to glide or fly through the air. Dinosaurs were a group of reptiles which varied in size from tiny creatures to species which were some five times the size of the modern elephants. Some dinosaurs were flesh eaters, some were plant eaters, and some probably ate a variety of different foods. Ichthyosaurs, plesiosaurs, pterodactyls, and dinosaurs all had become extinct by the end of the Mesozoic Era.

Fossil birds. The first fossils of a bird are found in rocks of Jurassic (Mesozoic Era) Age. This bird was about the size of a crow, had teeth, free claws on its wings, and other reptilian characteristics. It clearly indicated that it had come from reptilian ancestors. Other fossil birds are known from the Cretaceous Period and the Cenozoic Era.

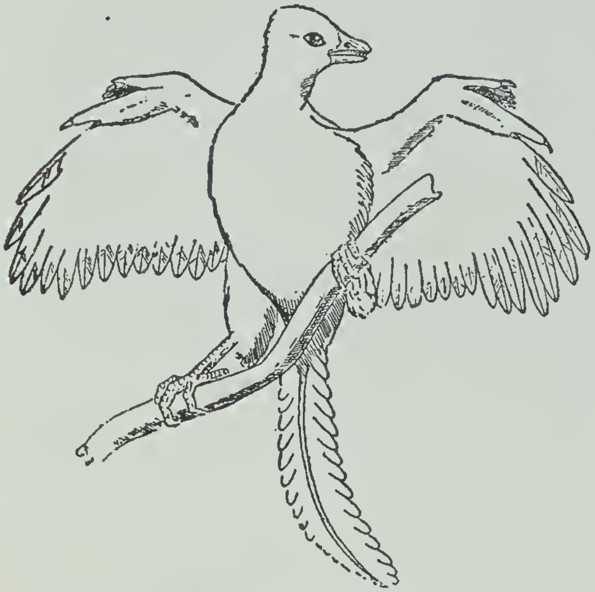


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FIGURE 188. Restoration of a primitive type of bird (Archæopteryx). Note the reptilelike characters, such as the presence of teeth.

Age of Mammals. Fossils of primitive mammals are found in rocks of Mesozoic Age. Apparently these mammals, which were small in size, had little chance to expand in numbers and species as long as the reptiles were flourishing. But at the end of the Mesozoic Era, when many of the reptiles became extinct, the mammal group began to expand rapidly. And the Tertiary Period became the Age of Mammals.

The fossil record of some kinds of mammals is quite complete. A good example is furnished by the case of the horse. This mammal was represented in early Tertiary time by a small, four-toed ancestor. As we follow the history of its development we find that it increased in size. The number of toes became reduced to three, and then to one. The modern type of horse had been developed after the close of the Tertiary Period. The fossil records of camels, elephants, and some other mammals also are very complete.

The first fossils of man are found in the deposits that are probably of Quaternary age. More specifically, in deposits

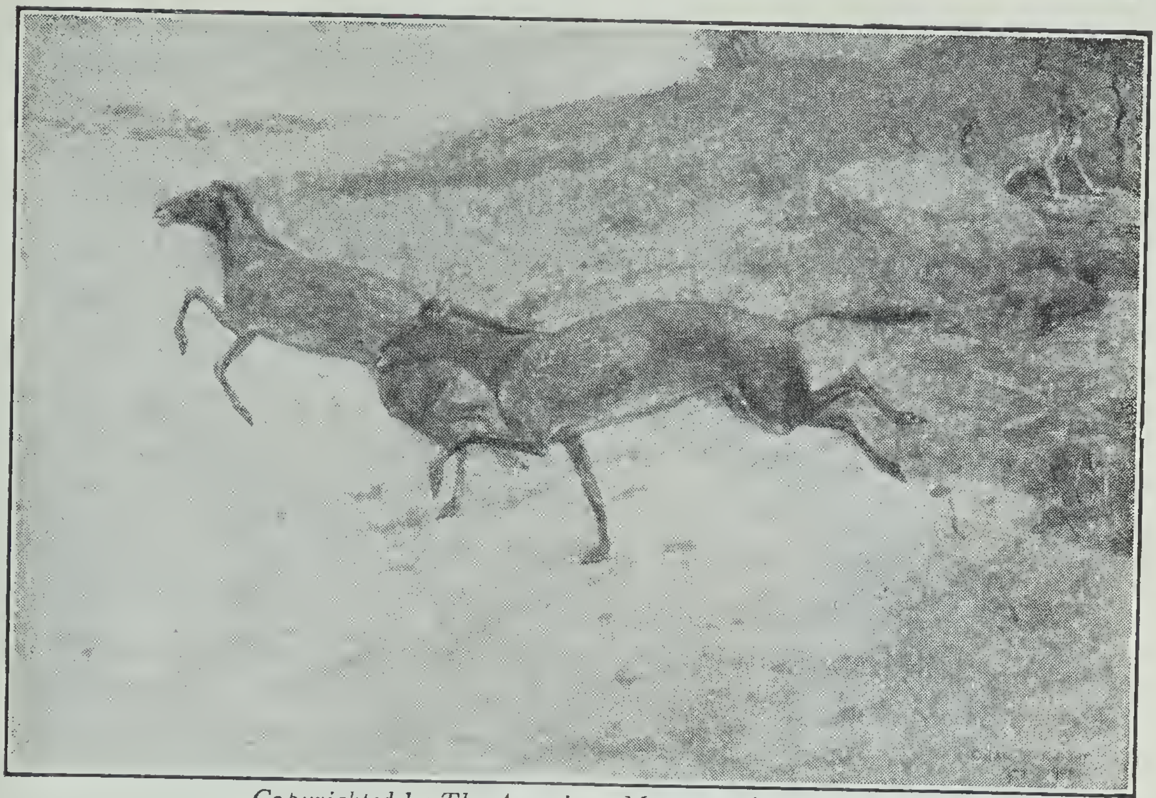

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FIGURE 189. A restoration of a prehistoric type of horse.

formed during the glacial epoch which occupied the first part of the Quaternary Period.

In summary, we may say that much of the evidence of racial change furnished by paleontology was not known during the time of Charles Darwin. Much of this knowledge has been acquired in comparatively recent times. Certainly it furnishes strong evidence in favor of the concept of racial change. We should note that although the fossil record indicates that many racial changes have occurred, it does not follow that the observed changes are wholly or satisfactorily explained by the theory of natural selection.

The fossil record indicates that certain groups of animals originated from older groups. Among the more obvious examples are the following:

1. Amphibians from fishes.
2. Reptiles from amphibians.
3. Birds from reptiles.
4. Mammals from reptilelike amphibians.

GEOGRAPHICAL DISTRIBUTION IS THE RESULT OF THE OPERATION OF NATURAL LAWS

Distribution. Practically all of the earth's surface is inhabited by some kinds of organisms. It formerly was thought that all species were to be found in the localities most favorable to their existences. But such is not the case. Some species that have been brought into new regions by man have proved to be much more successful in the new regions than they had been in their native regions. In some cases this has been unfortunate from the standpoint of man's interests, because the introduced species have proved to be pests.

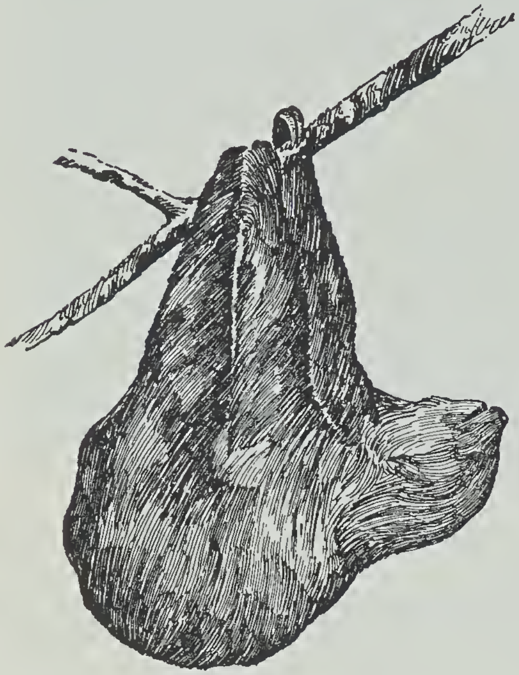

FIGURE 190. A sloth; a type of animal found in the jungles of Central and South America.

Climate and distribution. Climate was formerly supposed to determine the population of a region. Such is probably the case, but only to a certain limited degree. Camels and tigers, for instance, are often regarded as being tropical or subtropical species, yet they live in Siberia. And one sometimes can observe greater changes in fauna and flora by going east or west than by going north or south.

Dispersal. Most of the evidence gained from the study of geographical distribution indicates that the distribution of a species is the result of all the forces which have acted upon that species in the past. There must have been a center of dispersal for each species. When a new species proved to be successful it would tend to spread out along the lines of least resistance. Sometimes the distribution of a species might become very extensive. Meanwhile that species might die out in the region where it first appeared.

Barriers to dispersal. Certain factors serve as barriers or partial barriers to the dispersal of species. Some of the natural barriers are the following:

1. Oceans
2. Deserts
3. Extremes of temperature
4. Mountain ranges
5. Rivers
6. Prevailing winds
7. Character of the soil
8. Extremes of pressure

What may be a barrier to the dispersal of one species may not be a barrier to the dispersal of another species. The character of the soil may influence the dispersal of a plant species but *may not* be an important factor in influencing the dispersal of an animal species. Birds migrate across rivers, lakes, and even oceans, which would be fairly effective barriers to the dispersal of some other animals.

Means of dispersal. The means of dispersal among organisms are many and varied. Most birds are able to fly. For that matter, some mammals and many insects can fly. On the other hand, most mammals are dependent upon walking or running. The latter also is true of a great many reptiles. Some amphibians can swim; in some cases their eggs may be carried in the water. Fish and other lower vertebrates are able to swim in securing dispersal. They may, however, be limited in their distribution by the depth of the water, and also by the presence or absence of certain salts in the water.

Many of the invertebrates are aquatic. Some of them disperse by swimming, or are carried by water currents. As in the case of the fishes, their distribution is likely to be influenced by the depth of the water or the presence or absence of salt in the water. A good many of the invertebrates are parasitic, and these species may become dispersed through the dispersal of their hosts. Some of the protozoa and other small invertebrates are able to form cysts around themselves and may be carried for great distances by the wind while within the cysts.

The wind is a very important factor in the dispersal of plant species. Spores and some seeds may be carried for considerable distances. Some seeds may be carried by birds or other animals. For that matter, water birds may carry small aquatic animals or the tiny eggs of fish and other aquatic types.

Man has had a great deal to do with the distribution of plants and animals. Cultivated plants have been carried into all parts of the world. Incidentally, the seeds of many other plants have been carried about in the process of shipping cultivated plants from place to place. Domesticated animals also have been widely dispersed by man. And again, many species of animals, including a number of parasites, insect pests, and rodent pests have been carried about over the earth's surface.

Oceanic islands. A good deal may be learned by studying the plant and animal life of certain islands. Some islands are surrounded by deep water and probably never have been connected with any mainland. Such islands are called oceanic islands. What sort of living things are found upon oceanic islands? Are they what one might expect to find as a result of the operation of natural laws? Let us answer our questions by considering the case of Laysan Island.

Life on Laysan Island. Laysan Island lies in the Pacific Ocean about eight hundred miles northwest of Honolulu. It is a small island of coral formation, and its land rises only some twenty-five feet above the sea. At the time when the first studies of life on this island were made, there were no trees. However, there were several species of bushes, grass, flowering plants, and other smaller plants. There were a few insects and small invertebrates. There were fish and other aquatic forms in the shallow sea. All of these types could have reached the island because of natural factors. Plant seeds are carried by the wind, some insects can fly, fish can swim, and the eggs and adults of some aquatic species are carried by water currents.

But there were no mammals or reptiles on Laysan Island. It would be unlikely that members of these groups could cross the ocean barriers from any mainland to Laysan Island. Rats, mice, and rabbits were introduced to the island by man, but they were not a part of the native fauna.

Perhaps the most significant thing about the life of Laysan Island was the character of the bird life. The island served (and still does, but probably to a lesser extent) as a nesting place for many species of water birds, including albatrosses and terns.

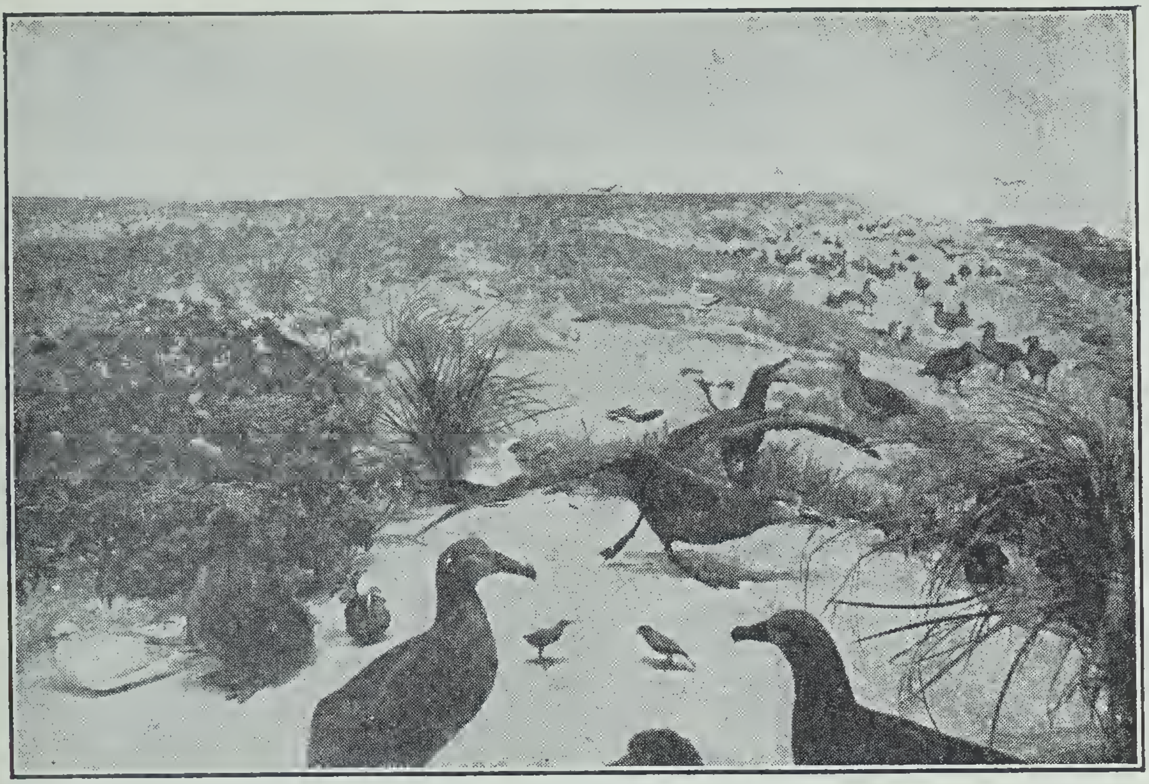

FIGURE 191. Life on Laysan Island. (Courtesy of Professor H. R. Dill.)

The presence of these birds was accounted for by the fact that they could fly. But there were five species of birds that were peculiar to Laysan Island. In other words, these five species were found in no other parts of the world. They were species that remained on the island continuously. In fact, one species — the Laysan rail — is a flightless bird. These five species had relatives in neighboring parts of the world, but they were distinct and separate species.

Galápagos Islands. All of this recalls the earlier observations of Charles Darwin in the Galápagos Islands, some six hundred miles from the west coast of South America. He found that the islands were populated by species related to the species on the mainland. But the species on the islands were distinct species. Furthermore, the species on one island often differed from those on another island.

Isolation. Now a group of animals or plants on an island, or otherwise separated from others of their kind, are said to be isolated. Isolation appears to be an important factor in favoring racial change. When all of the members of a species are living together in a continuous distribution, new variations are merged with the species. The average of the species may be changed, but this is not likely to be very noticeable. When a group of individuals become isolated, however, new variations remain peculiar to that group. They are more noticeable because they may be contrasted with the variations of the parent group.

Isolation and racial change. Many observations upon the effects of geographical isolation, similar to those mentioned above, have been made in different parts of the world. This great mass of evidence indicates that isolation is one factor in promoting racial changes. It also indicates that species originated in various places, and tended to disperse from those places of origin. The present distribution of a species is the result of all the forces that have acted upon that species in the past.

THE DEVELOPMENT OF EMBRYOS

Development of embryos. Another line of evidence which supports the concept of racial change has been obtained from the study of development among animals. In early development, a higher animal may pass through a number of structural stages which are characteristic of ancestral forms lower in the scale of classification. Perhaps an example will serve to define this situation.

The pig embryo. The evidences of the fossil record indicate that the mammals, such as the pig, are descended from reptilelike amphibians. The latter were developed from prehistoric amphibians, and the prehistoric amphibians were descended from some ancient fish types. The adult pig breathes through the agency of lungs, but in its early life, long before birth, it develops gill slits in the neck region. These gill slits disappear entirely before the pig is born. Their presence in early development suggests, however, relationship to fishlike ancestors.

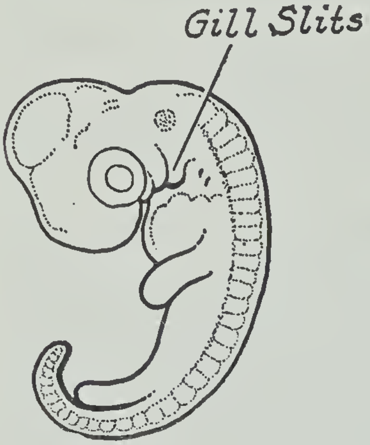

FIGURE 192. Diagram of a pig embryo, showing the gill slits which are present during early development.

The chick embryo.[1] We see similar evidence when we study a chick's development. The fossil record indicates that birds descended from reptiles, reptiles from amphibians, and amphibians from fish. In early development (long before hatching) the chick embryo has gill slits in the neck region.

Development of hearts. The study of early development in birds and mammals shows that their hearts pass through a two-chambered stage (like fish) and then a three-chambered stage (like amphibians). Finally, they become four-chambered. This again suggests relationship among fishes, amphibians, reptiles, birds, and mammals.

Blood relationships. There is an old saying that "blood will tell." Recently this has become very true. Studies by Landsteiner and others show that relationships of animals may be shown by the chemical nature of their blood. Karl Landsteiner of the Rockefeller Institute won the Nobel Award in 1930 for notable contributions to our knowledge in this field. He found that there are blood types which can be recognized by their chemical behavior. There are some remarkable outcomes of this discovery. For example, the blood of a domestic cat resembles more closely that of a tiger than that of a dog. Egyptian mummies have been shown to be related by blood to some modern peoples of Egypt.

Summary. Altogether, evidences from studies of anatomy, physiology, fossils, geographical distribution, development of embryos, and blood strongly support the concept of racial change. This does not mean, however, that racial changes have occurred as indicated by the theory of natural selection. This theory is merely one attempt to explain racial changes. The original theory has been modified by modern biologists. No doubt new discoveries will lead to other changes in the future.

SUGGESTED ACTIVITIES

Scientific methods

A scientist often makes controlled experiments in order to verify observations of things which occur in nature.

1. If a museum is available, study representatives of each of the larger plant and animal groups, noting similarities and differences in structure.

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[1] Domesticated chicken.

2. Collect fossils from some near-by stone quarry, or outcrop of rock.[1] Identify the phyla of some of the fossil organisms. Investigate the geological history of the region, and report to the class the probable period when these fossils were formed.
3. If a geological museum is available, study the fossil remains of various plants and animals. Compare the fossil types with related modern species.
4. After consulting the reading references at the end of this chapter, prepare a report on the ancestry of the horse, or the elephant, or the camel.
5. After consulting the reading references at the end of this chapter, prepare a report on extinct reptiles which lived during the Mesozoic Era.
6. Prepare lists of (*a*) species which have become extinct within historical time, and (*b*) species which have become greatly reduced in numbers.
7. Examine the embryos of two or three vertebrates (museum specimens, charts, or slides). Observe the presence of gill slits during certain stages of development.
8. Prepare a wall chart illustrating the type of heart structure in a fish, frog, reptile, bird, and mammal.

SUMMARY OF PRINCIPLES

1. Evidences of changes in nature are derived from many sources.
2. Changes have been observed in domesticated animals and cultivated plants within historical time.
3. The structures of plants show basic resemblances, and a graded scale of specialization from lower to higher. The structures of animals also exhibit these characteristics.
4. Classification is based upon certain structural resemblances; structures having the same origins.
5. The fossil record indicates that various species have lived in the past, many of which are now extinct. Some of these species left descendants which survive in the modern world.
6. Organisms which inhabit isolated regions give indication that racial changes are favored by isolation.
7. The distribution of a species is the result of all the forces which have acted upon that species in the past.
8. The development of the embryos of many organisms gives evidence of changes in structure from a simpler to a more complex form.

GUIDE QUESTIONS

1. Discuss evidences of racial changes which have occurred within historical time.

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[1] Note that not all rock formations contain fossils.

2. Name the four divisions of plants, beginning with the simplest types, and under each division indicate the important series and classes.
3. Arrange the following animals in a column in order of increasing complexity, and after each name write the name of the phylum: earthworm, grasshopper, frog, snake, elephant, starfish, Amœba, coral.
4. What do fossils indicate about racial change?
5. Do we find fossils of fish in rocks of the Cambrian Period? In what period do such fossils first appear?
6. What forms of animal life flourished when the great Mississippian and Pennsylvanian coal beds were deposited? How do we know?
7. What kinds of animals and plants were in existence during the Mesozoic Era?
8. Give an example of an isolated region and describe the kind of life found there.
9. What does geographical distribution indicate as to relationships of forms of life in different regions?
10. Name seven conditions which act as barriers to the dispersal of species.
11. Discuss the development of the heart in mammals and birds.

BOOKS TO READ

Lucas, F. A. *Animals of the Past.*
Parsons, G. *Stream of History.*
Shull, A. F. *Principles of Animal Biology.*
Woodruff, L. L. *Foundations of Biology.*

CHAPTER XXVII

MENDEL'S LAW AND HEREDITY

Problems:

1. What is Mendel's law of heredity?
2. To what extent may Mendel's law be used in solving human problems?
3. What is the "gene" in inheritance?

MENDEL'S LAW RESULTED FROM CAREFUL EXPERIMENTATION

Foreword. Gregor Johann Mendel (1822–1884) was an Austrian monk, who carried on extensive experiments with garden peas. Without doubt his work was looked upon as a harmless but rather useless hobby. Nevertheless, he was destined to make a remarkable contribution to our knowledge of heredity. Such cases are not uncommon in history. A research worker discovers some facts which at first may not appear to be of great consequence, but may prove to be very important when they are applied to the solution of human problems.

Mendel. Mendel crossed different varieties of peas and kept careful records of all of their descendants. From the results of his experiments, Mendel was able to state certain rules of heredity, which today make up what is known as "Mendel's law." Mendel's discoveries were published in 1866 in the *Transactions* of the Natural History Society of Brünn. At that time Brünn was in Austria — since the World War it has become Brno, Czechoslovakia.

At first (1866) Mendel's work attracted little more than local attention. Probably very few people of that day and age were in a position to appreciate its significance. As Walter[1] says: "Weismann had not yet led out the biological children of Israel through the wilderness upon that notable pilgrimage of fruitful controversy which occupied the last two decades of the nineteenth century."

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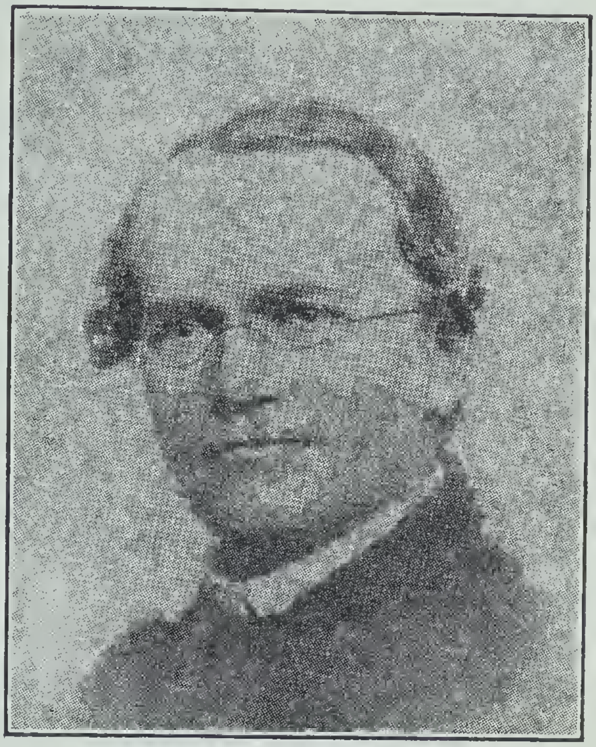
[1] Walter, H. E. *Genetics.*

Mendel's work received little or no public attention during the latter part of the nineteenth century. Meanwhile, Mendel died in 1884. Then his work was rediscovered in 1900 by Correns of Germany, DeVries of Holland, and von Tschermak of Austria. Soon afterward Davenport and Castle in the United States and Bateson in England began to study Mendel's law with special reference to heredity in animals.



American Museum of Natural History, New York.

FIGURE 193. Gregor Mendel, an Austrian monk, was born in 1822 and died in 1884. He experimented with garden plants in what is now Brno, Czechoslovakia. His experiments with garden peas were carried out with extreme care, and gave rise to the Mendelian laws of heredity.

MENDEL'S LAW DEALS WITH ALTERNATIVE INHERITANCE

Galton. In order that we may understand Mendel's law, it is desirable that we give some attention to a statement made by Sir Francis Galton (England), in 1888. When two individuals which differ with respect to a certain character (characteristic) are crossed, the offspring will be hybrids for the character in question. Supposing, for instance, that a plant having red flowers (pure) was crossed with a plant having white flowers (pure). The resulting offspring would be hybrids with respect to color.

Types of inheritance. Galton stated that hybridization, such as that referred to above, resulted in three types of inheritance: blending, particulate (mosaic), and alternative. Blending inheritance would occur when the parental differences were fused to produce an average type in the offspring, which would breed true. Galton thought that this type of inheritance occurred with respect to body height in man. The more we learn about heredity, the more we are forced to the conclusion that blending inheritance is a very rare type. It would appear that supposed cases of blending inheritance can be explained as complex cases of Mendelian inheritance.

Particulate or mosaic inheritance was supposed to occur when the parental differences appeared in the offspring in a sort of mosaic pattern: for instance, if the offspring of pure black and pure white animals were spotted black and white. Again, this appears to be a very rare type of inheritance in the light of modern studies. Supposed cases of particulate inheritance also have been explained as complicated cases of Mendelian inheritance.

Alternative inheritance would occur when the parental differences are not averaged or blended, but remain separate, and both parental types reappear in successive generations of offspring. This is the type of inheritance to which Mendel's law applies. And the facts indicate that this is the common type of inheritance among plants and animals. Since 1900 many cases of this type of inheritance have been discovered among many different organisms, including man.

Mendel's law. In substance, Mendel's fundamental law is as follows: When parents which are unlike with respect to a character are crossed (sexual reproduction), the offspring will appear to be like one of the parents with respect to the character in question. The parent which impresses the character upon the offspring is called dominant for that character — the other parent is termed recessive.[1] When the hybrid offspring of this first (F_1)[2] generation are in turn crossed, the offspring in the second generation (F_2) appear in the ratio of one pure dominant, two hybrids which look dominant, and one pure recessive.

These facts will become more understandable to us if we consider a specific case. Mendel found that tallness was dominant over dwarfness in garden peas. An individual plant might be "pure" tall or "pure" dwarfed, or hybrid, depending upon its inheritance. We express this in the following manner:

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[1] Similarly, the character impressed upon the offspring is called dominant — the opposing character is recessive.

[2] F_1 stands for "filial first." In other words, the first generation of offspring. F_2 refers to the second generation of offspring.

T = tall (dominant)
d = dwarfed (recessive)
TT = pure tall
Td = hybrid
dd = pure dwarfed

Two parents which are unlike with respect to a character would be a pure tall (TT) and a pure dwarfed (dd). When these are crossed, all of the offspring (F_1 generation) are hybrids (Td). That is, they inherit for tallness from one parent, and for dwarfness from the other parent.[1]

For the sake of simplicity we shall assume that there are four offspring in each generation. We may determine the result of a cross between a pure tall and a pure dwarfed in the following manner. Write the combinations TT and dd on a sheet of paper, one above the other, as in the example shown below. Take one of the letters of the lower pair, and combine it with each letter in the upper pair. It will be seen that this gives two combinations of Td. Then take the remaining letter of the lower pair, and combine it with each letter of the upper pair. In the example shown this results in two more Td combinations. In other words, the four combinations which result from the crossing of TT and dd are all Td.

$$\frac{\begin{array}{c}\text{TT}\\ \text{dd}\end{array}}{\text{Td} + \text{Td} + \text{Td} + \text{Td}} \quad \text{or} \quad \frac{\begin{array}{c}\text{TT}\\ \text{dd}\end{array}}{4\ \text{Td}}\ (F_1\ \text{generation})$$

In the above example, the hybrid offspring (Td) of the F_1 generation *are tall in appearance.* Each one, however, carries the determiner (d) for dwarfness. Since tallness is dominant, the individuals become tall in appearance. They appear to be as tall as the parent TT, to all intents and purposes.

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[1] A hybrid is the product of parents which are unlike in *one or more characters.*

When two hybrid offspring of the F_1 generation are crossed, the F_2 generation is produced.

$$\begin{array}{c} \text{Td} \\ \text{Td} \\ \hline \end{array}$$

In the above example, we place one Td above the other, and draw a line. Beneath this line we enter the resulting combinations of the cross. These are determined as in the preceding example. If we combine the T of the lower pair with each letter of the upper pair, we get two different combinations — TT and Td. Then if we combine the d of the lower pair with each letter of the upper pair, we get the combinations Td and dd. We now have the following results:

$$\begin{array}{ll} \text{Td} & \\ \text{Td} & \\ \hline \text{TT} + \text{Td} & \\ & \text{Td} + \text{dd} \end{array}$$

We may now draw another line, and add our results:

$$\begin{array}{ll} \text{Td} & \\ \text{Td} & \\ \hline \text{TT} + \text{Td} & \\ & \text{Td} + \text{dd} \\ \hline \text{TT} + 2\ \text{Td} + \text{dd} & (F_2 \text{ generation}) \end{array}$$

These results represent the typical F_2 generation ratio. There is one pure dominant (TT), two hybrids which appear tall (2 Td), and one pure recessive (dd). The pure recessive would be the only type that would appear dwarfed.

Another way to determine the result in the F_2 generation is by means of the so-called "checkerboard" method. T and d are the two possible contributions of each hybrid parent. We construct a checkerboard of four squares, and place the T and d of one parent along one margin. The T and d of the other parent are placed along another margin, as in the example. Let us mark one square with the figure 1.

	T	d
T		1
d		

This square represents one offspring. To determine the inheritance (for height) of this offspring, we proceed as follows: We enter in square 1 a d, corresponding to the d on the upper margin. Then we enter a T, corresponding to the T on the left-hand margin. This gives the result:

	T	d
T		Td
d		

Using the same general method, we may now fill in the remaining squares. It will be seen that the result is the same as that obtained by using the preceding method (see page 436).

	T	d
T	TT	Td
d	Td	dd

Summarizing the combinations within the squares, we have the following: TT + 2 Td + dd. This will be recognized as the typical F_2 generation ratio.

In the F_2 generation, three individuals would appear tall for every individual that appeared dwarfed. Out of every 1000 plants (peas) in the F_2 generation, we might expect about 750 to *appear* tall. They are tall, as far as external appearances are concerned. Of the 750, however, about 250 would be pure tall (TT) in their inheritance. Approximately 500 would carry the recessive factor, and would be hybrids (Td). Some 250 out of the 1000 would appear to be dwarfed, and would in fact be *pure* dwarfed (dd).

MENDEL'S LAW INVOLVES THREE CONCEPTS

Analysis of Mendel's law. An analysis of Mendel's law shows that it involves three concepts. These are:

1. The concept of unit characters
2. The concept of dominance
3. The concept of segregation

Unit characters. The first concept holds that an organism is made up of certain characters which are inherited as units. We now know that a number of genes may be involved in the inheritance of a single unit character. Later studies have also revealed that certain characters are dependent upon the presence or absence of other characters in the process of inheritance.

Dominance. In Mendelian inheritance certain characters are dominant over others. Thus in Mendel's peas, tallness is dominant over dwarfness, and dwarfness is called a recessive character. A recessive character appears only in the absence of the corresponding dominant character. We note that in the case of Mendel's peas, a Td combination produces a tall plant in so far as external appearance is concerned. Only the dd combination produces a plant which *appears* dwarfed. In this case, when an organism *appears* recessive (dwarfed), we have assurance that it is a pure recessive (dd). If it appears dominant (tall), it may either be a pure dominant (TT), or a hybrid (Td).

Segregation. During maturation of either the sperm or the ovum, the genes become separated from each other. New, and usually different, combinations of genes result when mature sperms and ova unite in fertilization. Since there often are many genes, the possible number of different combinations is very great in many species. The fact that such new combinations of genes are formed indicates that offspring probably will not be exactly like either of their parents. In other words, heredity provides for variation from the parental types, as well as resemblance to the parental type.

Cases of Mendelian inheritance. Since Mendel's work was rediscovered in 1900, many cases in which Mendel's law applies have been discovered. These cases occur both among plants and among animals. The following table indicates a few of these discoveries:

TABLE VII. DOMINANT AND RECESSIVE CHARACTERS

ORGANISM	DOMINANT CHARACTER	RECESSIVE CHARACTER
sunflower	branched	unbranched
wheat	susceptibility to rust	immunity to rust
cotton	colored lint	white lint
silkworm	yellow cocoon	white cocoon
Drosophila (fruit fly)	red eyes	white eyes
guinea pig	short hair	angora hair
canary	crest	plain head
mouse	normal habit (gait)	waltzing habit (gait)
guinea pig	three toes	four toes
a variety of cattle	hornless	horns
man	fingers and toes with two joints	fingers and toes with three joints
man	normal pigmentation	albinism

Incomplete dominance. One interesting case of color inheritance occurs in the flower known as the four-o'clock (Mirabilis). When red and white flowers are crossed, the resulting hybrid offspring are pink:

$$\begin{array}{rc} & \text{RR} \\ & \text{WW} \\ \hline F_1\ldots\ldots & 4\ \text{RW (pink)} \end{array}$$

But when any two of these pink hybrids are crossed, the F_2 generation appears in the ratio of one red, two pink, and one white:

$$\begin{array}{rl} & \text{RW} \\ & \text{RW} \\ \hline & \text{RR} + \text{RW} \\ & \qquad\qquad \text{RW} + \text{WW} \\ \hline F_2\ldots & \text{RR (red)} + 2\ \text{RW (pink)} + \text{WW (white)} \end{array}$$

This is the way that alternative inheritance works out, except that in most cases one character dominates the other. The above case is referred to as *incomplete dominance.* This and some other cases of incomplete dominance have been discovered since Mendel's time. In these cases it is possible to distinguish between the hybrids and the pure types upon the basis of appearance. However, the hybrid type is not as clearly marked in all cases as it is in the case of the four-o'clock mentioned above.

KNOWLEDGE OF MENDEL'S LAW MAY BE APPLIED TO THE SOLUTION OF CERTAIN LIFE PROBLEMS

Knowledge of Mendel's law has possibilities of great practical value in developing desirable types of domesticated animals and cultivated plants. Let us consider a *hypothetical case* as an illustration of this point.

Value of Mendel's law. Suppose that we start with a stock in which not all individuals are of the same color. The colors are black (B) and white (w). We have determined by experimenting with crosses that B is dominant over w. But at the moment the stock consists of about three black individuals to every white individual. Our knowledge of Mendel's law tells us that the ratio of individuals is as follows:

$$\text{BB} + 2\ \text{Bw} + \text{ww}$$

three black: one white

If we wish to develop a pure white type the problem is very simple. We know that all individuals that appear white are pure white (ww) in their inheritance; for the recessive characteristic can appear only in the absence of the dominant factor. Hence we select white individuals as a nucleus from which the white stock is to be developed. Crossing such individuals will result in the production of white offspring:

$$\begin{array}{r} \text{ww} \\ \underline{\text{ww}} \\ 4\ \text{ww} \end{array}$$

A pure dominant strain (BB) is somewhat harder to develop. We may choose a number of black individuals at random, but we cannot tell whether they are BB or Bw. In either case they are black in appearance. We are forced to depend upon experimental crosses to determine whether or not certain individuals are pure black in their inheritance. We select a number of black individuals and cross them with white individuals. Two possible situations may occur:

$$\text{(I)}\ \begin{array}{c} \mathrm{BB} \\ \mathrm{ww} \\ \hline 4\ \mathrm{Bw} \end{array} \qquad\qquad \text{(II)}\ \begin{array}{c} \mathrm{Bw} \\ \mathrm{ww} \\ \hline \mathrm{Bw} + \mathrm{ww} \\ \mathrm{Bw} + \mathrm{ww} \\ \hline 2\ \mathrm{Bw} + 2\ \mathrm{ww} \end{array}$$

If the individual being tested is a BB (case I), it may be crossed with a ww, and all offspring will be black, although they actually are hybrids (Bw). But if the individual being tested is a Bw (case II), crossing with a ww will produce offspring half of which are white (ww), and half of which are black (Bw). Therefore, we discard the black individual which produced the results obtained in case II. We know that the individual tested in case I not only appears to be black but is pure black in its inheritance (BB). This individual, and other individuals similarly tested, become the nucleus for our pure black race.

We must remember that the above case is only a hypothetical case. Nevertheless, it illustrates the fact that the principles involved in Mendel's law may be used with profit in solving some of the ordinary problems of life. Unfortunately, most cases of inheritance among higher animals are much more complex than the case indicated above. More than two factors such as B and w are involved in the production of a character. In such cases, however, the basic principles involved remain similar to those that we have studied.

THE GENES ARE THE UNITS OF INHERITANCE

Mendel's work gave rise to the science of genetics.[1] Many important discoveries followed the revival of Mendelism in 1900. Many cases of supposed blending or particulate inheritance have proved to be complex cases of Mendelian (alternative) inheritance, in which more than one hereditary unit is responsible for the inheritance of a character.

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[1] The study of heredity.

Genes. As we have previously learned, these hereditary units are now known as "genes." They are supposed to be structures or entities located in the chromosomes; sometimes there are many genes in a single chromosome. A certain character, such as human stature, may not depend upon the inheritance of two contrasting genes such as T or d, but upon a number of genes. In fact, a character may depend upon a "complex of genes," and the interaction of these genes.

The fruit fly. Much of our modern knowledge of heredity has been developed from the study of the celebrated fruit fly (Drosophila) by Prof. T. H. Morgan and his followers. This fly proved to be a good experimental species because it could be raised rapidly in the laboratory with comparative ease, and in large numbers. It has also exhibited a wide range of variations.

Summary. The science of genetics has progressed rapidly since the beginning of the twentieth century, when the work of Mendel began to receive attention. Mendel's work served as a foundation which has been extended to the study of heredity in many species. Knowledge of heredity has proved to be of great importance in human affairs, and especially in connection with the development of desirable cultivated plants and domesticated animals. One of the most important discoveries made since Mendel's time has been in connection with the "gene theory." A gene is probably a chemical entity, located in a chromosome, and responsible for the inheritance of a certain characteristic. The exact nature of the gene is not yet fully understood. In the discussion that follows, we shall study some of the more recent knowledge of this subject.

SUGGESTED ACTIVITIES

Scientific methods

A scientist is careful to avoid allowing his feelings or personal interests to interfere with the reporting of facts.

1. After consulting the reading references at the end of this chapter, con-

struct a table of human characteristics that are inherited according to the Mendelian ratio, indicating dominant and recessive traits. (See page 439.)

2. After consulting the reading references at the end of this chapter, report in detail some of the experiments of Morgan and Davenport.
3. Study charts or lantern slides which illustrate Mendel's law.
4. Investigate the meanings of the following terms: phenotypes, genotypes, dihybrids, and trihybrids.
5. Self-testing exercise: Which combination from Column A will produce each of the results listed under column B?

A	B
1. TT + dd	All offspring are TT
2. TT + TT	All offspring are dd
3. Td + Td	All offspring are Td
4. dd + dd	
5. Td + dd	

6. T is dominant; d is recessive. Td and TT are crossed. Out of four offspring, how many will appear to be tall, and how many will appear to be dwarfed? How many will be hybrids?
7. B is dominant (Black); w is recessive (white). Bw and ww are crossed. Out of four offspring, how many will appear black, and how many will appear white? How many will be hybrids?

SUMMARY OF PRINCIPLES

1. The first satisfactory explanation of the transmission of characters from parents to offspring was proposed by Gregor Mendel in 1866.
2. Mendel's laws are generalizations based upon a large number of facts which were obtained by careful experimentation with plants, especially garden peas.
3. Mendel's principles usually are formulated in three laws concerning: (1) unit characters, (2) segregation, and (3) dominance.
4. The law of unit characters holds that the qualities (characters) of an individual organism (for the most part) are transmitted as separate units.
5. The law of segregation states that in the process of forming the mature sex cells, the genes become separated out, to form new combinations in fertilization.
6. The law of dominance states that of two contrasting characters one (called the dominant) suppresses the other (recessive); recessive traits "appear" only in the absence of dominant factors.
7. Incomplete dominance refers to the fact that in a few cases the hybrids exhibit some features of both dominant and recessive characters.

8. An individual may have two dominant factors (called a pure dominant), or two recessive factors (called a pure recessive), or one factor of each dominant and recessive (called a hybrid).
9. The modern practices of breeding animals and plants are based upon Mendel's principles.
10. Since Mendel's time, further studies have given us more exact knowledge of chromosomes and genes, and have modified some of the older concepts.

GUIDE QUESTIONS

1. Describe briefly the work of Gregor Mendel.
2. State the three principles involved in Mendel's laws.
3. Give an example of two contrasting characters in garden peas.
4. If two contrasting characters were M and n of which M is dominant show by diagram the results of:
   a. crossing an MM with an nn (MM + nn).
   b. crossing two hybrids (Mn + Mn).
   c. crossing MM with Mn (MM + Mn).
5. What is meant by F_1 and F_2 generations?
6. Explain what is meant by incomplete dominance, and illustrate by means of red and white four-o'clocks.
7. Discuss how knowledge of Mendel's principles may be used in developing useful types of domesticated animals and cultivated plants.
8. What is the relationship of the gene to the unit character?
9. Why has the fruit fly been widely used in studying heredity?

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Walter, H. E. *Genetics.*
Wheat, F. M., and Fitzpatrick, E. T. *Advanced Biology.*

CHAPTER XXVIII

MODERN KNOWLEDGE OF HEREDITY

Problems:

1. What is "heredity"?
2. How is sex determined in various species?
3. What are "sex-linked" characters in inheritance?
4. What may be learned from the study of twins?
5. What effects do heredity and environment have in molding the development of an organism?

HEREDITY IS THE PROCESS BY MEANS OF WHICH CHARACTERISTICS ARE CONVEYED TO FUTURE GENERATIONS

Foreword. In previous chapters we have learned that some of the earlier concepts regarding heredity and racial changes have been modified from time to time as we have become aware of new facts. Thus the theory of natural selection has been altered from its original form. We have learned to question the possibility of the inheritance of acquired characteristics. We have come to regard the gene as being the unit of inheritance.

Heredity. Heredity was once defined as the "tendency of the young to resemble the parents." We should now discard this definition because we know that heredity will in itself prevent the young from resembling the parents in the cases of some characteristics. Rather, heredity is *the mechanism by means of which certain characteristics are conveyed to future generations.* And we have seen that in cases of Mendelian inheritance characteristics do not always *appear* in all generations.

We have seen that offspring may differ from their parents because they possess recombinations of genes coming from the two parental sources. We have also learned that the so-called unit character is not necessarily produced by a single gene. It may result from the combination of a few or many genes in the individual.

One of our popular fallacies is to assume that heredity is all-important in molding the individual. Another is to assume that environment is all-important. Both heredity and environment are important to a varying degree, depending upon the characteristic and the species under discussion. This can be made clear to us by examining the inheritance of sex and certain structures in different organisms.

IN SOME SPECIES SEX IS DETERMINED BY HEREDITY

Sex chromosomes. In the accompanying figure it will be seen that Drosophila has eight chromosomes, arranged in four pairs. Also that the chromosomes of a male differ from the chromosomes of a female. The female has two *x* chromosomes, whereas the male has one *x* chromosome and one *y* chromosome. In this case, the determination of sex depends upon whether the individual has one or the other of these two combinations of chromosomes. A fertilized ovum bearing two *x* chromosomes will develop into a female. A fertilized ovum bearing one *x* and one *y* chromosome will produce a male.

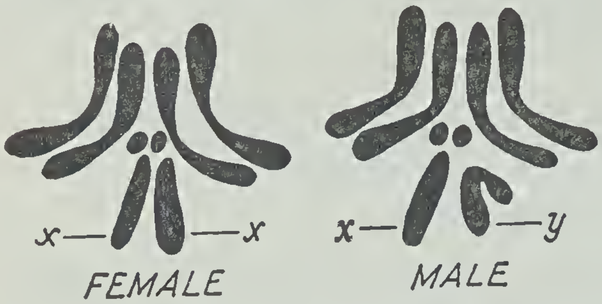

FIGURE 194. The chromosomes of a fruit fly (Drosophila melanogaster). Note that the male has one *x* chromosome and one *y* chromosome, whereas the female has two *x* chromosomes.

A similar situation occurs in the determination of sex in man. The fertilized ovum bearing an *x* and a *y* chromosome becomes a male; the fertilized ovum containing two *x* chromosomes becomes a female. In some insects and birds, a male has two *x* chromosomes and a female has a single *x* chromosome. In another insect type, the male has four *x* and one *y* chromosomes and the female has eight *x* chromosomes. In all of the foregoing cases it is evident that the combination of chromosomes determines sex. A given combination will produce a given sex regardless of other factors, such as changes in the environment.

Environment and fertility. On the other hand, environment is very important in the development of fertility among honeybees. The so-called "queen" bee develops from a fertilized egg, but the egg is hatched in a special type of egg cell and the larva is fed upon bee jelly. The worker type of bee comes from a fertilized egg also, but the egg is not hatched in a special cell, and the larvæ are fed pollen and honey. The "queen" bee is a fertile individual, but the workers are not fertile (do not take part in the process of reproduction).

SOME CHARACTERISTICS ARE SEX-LINKED IN INHERITANCE

Experiments and scientific data indicate that a number of characteristics of different species are sex-linked in their inheritance. An example is furnished by human color blindness. In this and similar cases, the genes producing the characters are located in the sex chromosomes.

It appears that the gene for color blindness occurs in the so-called x chromosome, and that color blindness is recessive. The character does not appear in the female unless it is represented in both x chromosomes. The male, as we have seen, has only one x chromosome. If this chromosome carries the factor for color blindness, a color-blind male is produced.

If:

x_1 represents a chromosome carrying the color-blind gene.
x and y represent chromosomes with a normal gene in place of the color-blind gene.

Then:

xx represents a normal female.
x_1x represents a female that appears normal although having a color-blind gene for each pair of sex chromosomes.
x_1x_1 represents a comparatively rare combination in the female, resulting in the appearance of color blindness.
xy represents a normal male.
x_1y represents a color-blind male.

Sex-linked characters. The inheritance of a number of other characteristics is known to be sex-linked. In fact, some fifty characters are sex-linked in Drosophila. Some of such characters are dominant and others are recessive in their hereditary behavior.

THE ORGANISM IS THE PRODUCT OF DEVELOPMENT

(And development depends upon heredity and environment)

Among many of the plants and the simpler animals, environment is exceedingly important in determining the physical make-up of the individual. This effect becomes less marked and heredity becomes more important in determining structural characteristics of the more complex animals.

Human characters. We have seen that differences in sex are determined by heredity in the case of man. So too are such defects as color blindness, the bleeding disease known as hemophilia, dwarfism, some mental defects, and such abnormal structures as the development of webbed feet or hands, six fingers or toes, or fingers shortened by the absence of the terminal portions. Eye color, hair color, and stature in man, appear to be due to hereditary factors, at least in many cases. Stature, including abnormal stoutness or abnormal slenderness, may be due directly to defects in the development of certain ductless glands. However, the glandular defects may in turn be inheritable.

Diseases. It is quite true that many human diseases are greatly influenced by environmental factors. At the same time they also may be in part due to the heredity of the individual. For example, in our study of the germ concept of disease we shall learn that some individuals are much more susceptible to tuberculosis than are others. Not that they inherit the disease from their parents, but their inherited physical make-up is such that they are likely to contract the disease, perhaps soon after birth. They inherit a physical weakness which makes them susceptible to tuberculosis, but they do not inherit the disease itself.

It also appears that some combinations of human genes produce individuals who are relatively susceptible to such diseases as cancer, plague, pneumonia, and smallpox. It does not necessarily follow that such individuals will develop the diseases to which they are susceptible. In a favorable environment the individual may avoid the development of the disease in question.

Mental defects. Certain mental defects undoubtedly are inheritable. These include types of feeble-mindedness, imbecility, idiocy, and insanity. The well-known cases of the Kallikak and

Jukes families are often used to illustrate the inheritance of feeblemindedness and moronism, the latter being a type of feeblemindedness which is not far removed from the normal mental condition.[1]

Identical twins. Interesting and significant data have come from the study of identical twins. Such twins are formed when a fertilized ovum divides into two parts which separate, or perhaps when a very young embryo divides in this manner. Hence identical twins have the same sets of genes — in other words, they have the same inheritance. Ordinary twins form from two distinct fertilized ova. It is highly probable that the genes will differ in two such individuals of the latter type.

In general, we find that identical twins, in the case of human beings, are very much more alike than are ordinary twins. Identical twins always are of the same sex, they have the same skin, hair, and eye colors, they agree as to stature and appearance, including abnormalities, they even tend to agree as to illnesses. Their footprints, handprints, and *even fingerprints* are very similar.

Lange, a German investigator, has made a study of crime and delinquency among ordinary and identical twins. He reports upon thirteen pairs of supposedly identical twins and seventeen pairs of ordinary twins.[2] Ten pairs of the identical twins had similar records of crime and delinquency. In two of the other three cases one individual had suffered a head injury, and in the case of the third pair one individual had a goiter. On the other hand, in fifteen of the seventeen pairs of ordinary twins there was no agreement as to crime or delinquency.

Summary. We probably should note that variation constantly produces new types. Some of these variations are desirable because they are suitable to the environment. Other variations are not suited to the environment, and in a state of nature individuals having such variations tend to be eliminated. We have learned that when a species of plant or animal is brought under cultivation or domestication, it receives a varying degree of protection from man. Thus it is that many varieties of cultivated and domesticated species that would not survive in a state of nature, continue to exist. So, too, in the case of man, individuals are kept alive through the application of medical knowledge, many of whom probably could not survive if forced to live apart from modern civilization.

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[1] Some writers have defined the moron as a person whose mental age is from eight to twelve years.

[2] Pairs of twins were selected in which at least one member of each pair had a criminal record. This ruled out many pairs of twins who had no contact with crime.

We cannot, however, view the individual except in terms of its environment. Heredity may be of a good or desirable type, but an unfavorable environment may result in early death or faulty development. Good environment often is essential to the development of desirable structures, habits, and traits. On the other hand, good environment can do little in many cases when heritage is of an undesirable type. The adult individual is the product of development, and development depends upon the combined effects of heredity and environment.

SUGGESTED ACTIVITIES

Scientific methods

A biologist classifies organisms according to their structural similarities.

1. In several bottles closed with cotton wads, raise some fruit flies, using bananas as food. Study their life history and characters. Look up Morgan's experiments with these organisms.
2. After reference to the table on page 439, explain the following:
   a. Unbranched sunflowers continue to produce unbranched offspring, but branched sunflowers often yield seeds which produce unbranched sunflowers.
   b. Once in a very great while a human albino appears in some family.
3. After reference to page 447, discuss why color blindness is more common among males than among females.
4. After consulting the reading references at the end of this chapter, discuss longevity (long life) as a character which "runs" in families.
5. Select examples of animals or plants. Study them and note ten or more characteristics which are possessed by one species, and two or more characteristics in which variation is observed among the members of the same species.

6. After consulting a textbook of zoology, report upon the production of queens, workers, and males in a honeybee colony.

SUMMARY OF PRINCIPLES

1. Heredity is the process by which characteristics are conveyed to future generations.
2. In some species sex is determined by the processes of heredity.
3. Some characters are sex-linked in inheritance.
4. Many human characteristics are inheritable.
5. Most diseases are not inherited as such, but the susceptibility to disease may be inherited in the character of certain cells or structures.
6. Certain human mental defects are inheritable.
7. Identical twins are two individuals resulting from one fertilized egg that gives rise to cells which separate to form two embryos; ordinary twins are individuals resulting from the fertilization and development of two different egg cells. Some knowledge of the relative influences of heredity and environment has been derived from the study of identical twins.
8. Both heredity and environment contribute to the development of an individual.

GUIDE QUESTIONS

1. Why may offspring differ from their parents as a result of heredity?
2. What determines sex in man? In a fruit fly (Drosophila)?
3. What evidence is there in the case of honeybees that food influences development?
4. How is sex involved in the inheritance of color blindness (man)?
5. What human defects may be inherited?
6. What is meant by "susceptibility to disease"?
7. Distinguish between "ordinary" and "identical" twins.
8. What did Lange's investigation of twins indicate?
9. Are all domesticated animals well fitted to survive in a state of nature?
10. Upon what two general factors does development depend?

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UNIT VII

PLANTS AND ANIMALS IN RELATION TO HUMAN AFFAIRS

WE NOW have completed our survey of the general structures and functions of plants and animals. At various points in this study it has come to our attention that certain types of plants and animals are of importance in human affairs. Some species are parasitic upon man, others attack his domesticated animals and cultivated plants. Certain species are utilized by man in providing food and various articles of commerce.

In the discussion which follows, we shall attempt to consider the use and control of various plants and animals which are of economic importance. What plants are of value and why? Why is it necessary to control, or to reduce, the numbers of certain plants? What animals are parasitic upon man or his domesticated animals? What animals attack crop plants? What animals are of value to man, either because they are used to provide desirable articles of commerce, or because they destroy undesirable species of animals? To what extent may we conserve the numbers of desirable plants and animals?

We have learned that man has not as yet succeeded in controlling all of his parasitic enemies. In this unit it shall be our purpose to study the relationships of certain small parasites, chiefly bacteria, to human diseases. What diseases are produced by tiny organisms such as these? How and to what extent may we secure protection against our parasitic enemies?

In concluding our study we shall wish to summarize our knowledge of the relationship of heredity and environment to human affairs. How may this knowledge be used to advantage? Which desirable and undesirable characteristics are inheritable? How may biological knowledge be used to improve the conditions of life?

CHAPTER XXIX

THE VALUE OF PLANTS

Problems:

1. What foods and other materials come from plant sources?
2. How is climate related to agriculture?
3. Why are some bacteria of value to man?

MANY PLANTS ARE USEFUL TO MAN

Foreword. In our preceding studies we have learned that green plants make foods from inorganic materials. All animal life is dependent upon this basic food supply. Man is no exception to the rule; his foods come directly or indirectly from green plants.

Cereals. In this study of useful plants let us first give attention to some cultivated varieties. In 1938, cereal production in the United States was about as follows:

PRODUCT	QUANTITY (bushels)	ESTIMATED VALUE (dollars)
Corn	2,542,238,000	1,279,711,000
Wheat	930,801,000	514,231,000
Oats	1,053,839,000	229,895,000
Barley	252,139,000	94,153,000
Rice	52,303,000	30,848,000
Rye	55,039,000	18,881,000

Other Products. Some other plant products produced in the United States in 1938 were approximately as follows:

PRODUCT	QUANTITY (units)	ESTIMATED VALUE (dollars)
Tobacco	1,455,970,000 (lbs.)	288,047,000
Lumber (1937)	25,997,000,000 (board feet)	
Cotton	12,008,000 (bales)	517,892,000
Apples	78,675,000 (bu.)	55,072,000
White potatoes	369,297,000 (bu.)	210,153,000
Sweet potatoes	76,647,000 (bu.)	56,482,000
Hay (1939)	84,022,000 (tons)	571,349,000
Sugar cane and beets (38–39)	2,383,000 (tons)	
Flax	8,171,000 (bu.)	13,161,000

The foregoing figures indicate the very great economic value of some plants. They refer to species of plants which have been brought under cultivation. In the United States vast areas are under cultivation for agricultural purposes. In addition are the extensive areas of poor land where cattle and sheep get their living from grasses. The railroads, the steamships, our grain elevators, and our great trade centers ultimately depend upon the plant products of the country.

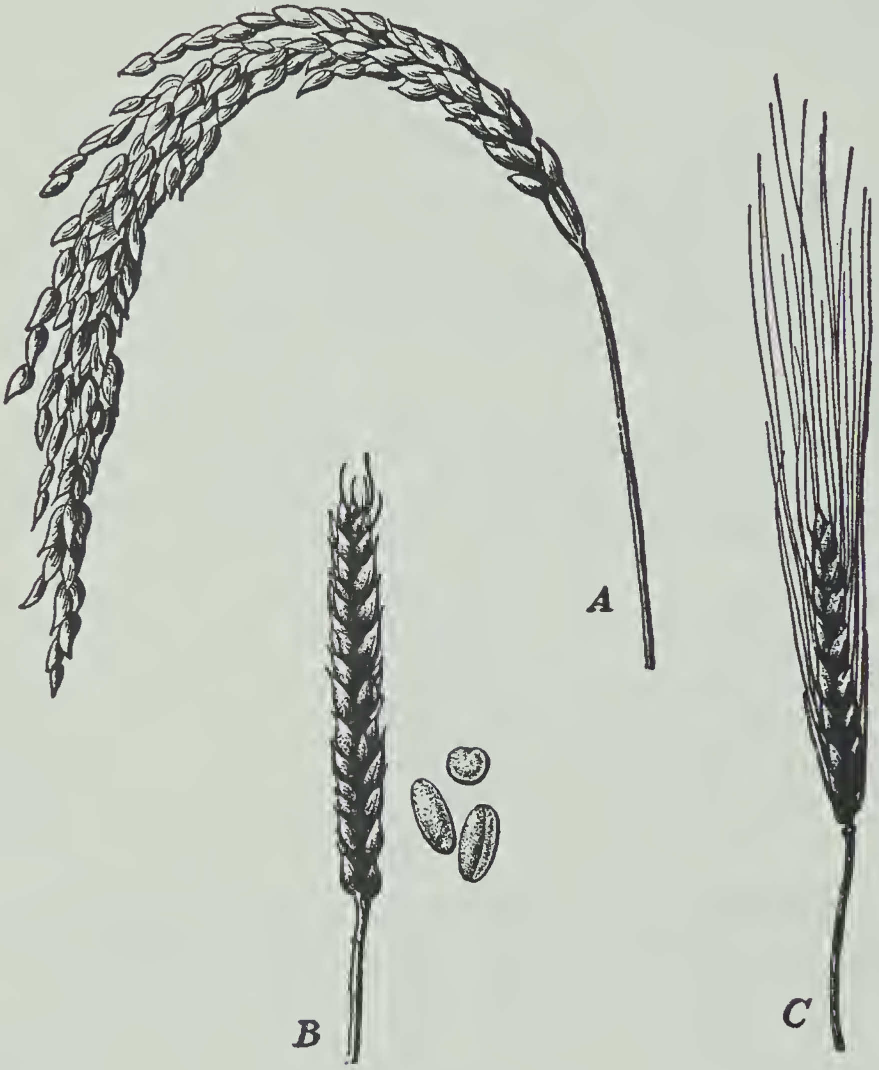


FIGURE 195.
A. Cultivated rice. *B*. Cultivated wheat. *C*. Cultivated barley.

Sugar. Louisiana and Texas produce annually about one billion pounds of sugar. Cuba and Puerto Rico produce even more. This sugar is a carbohydrate obtained from sugar cane.

After the juice containing the sugar is extracted from the cane, the crushed stems are used for various purposes, among which is the manufacture of fiber board for walls and partitions. Sugar beets also yield sugar, and are raised extensively in parts of the Midwest and the Rocky Mountain area. Beet pulp is used as a stock feed. The people of the United States consume about three billion pounds of sugar each year, or about twenty-five pounds per capita.

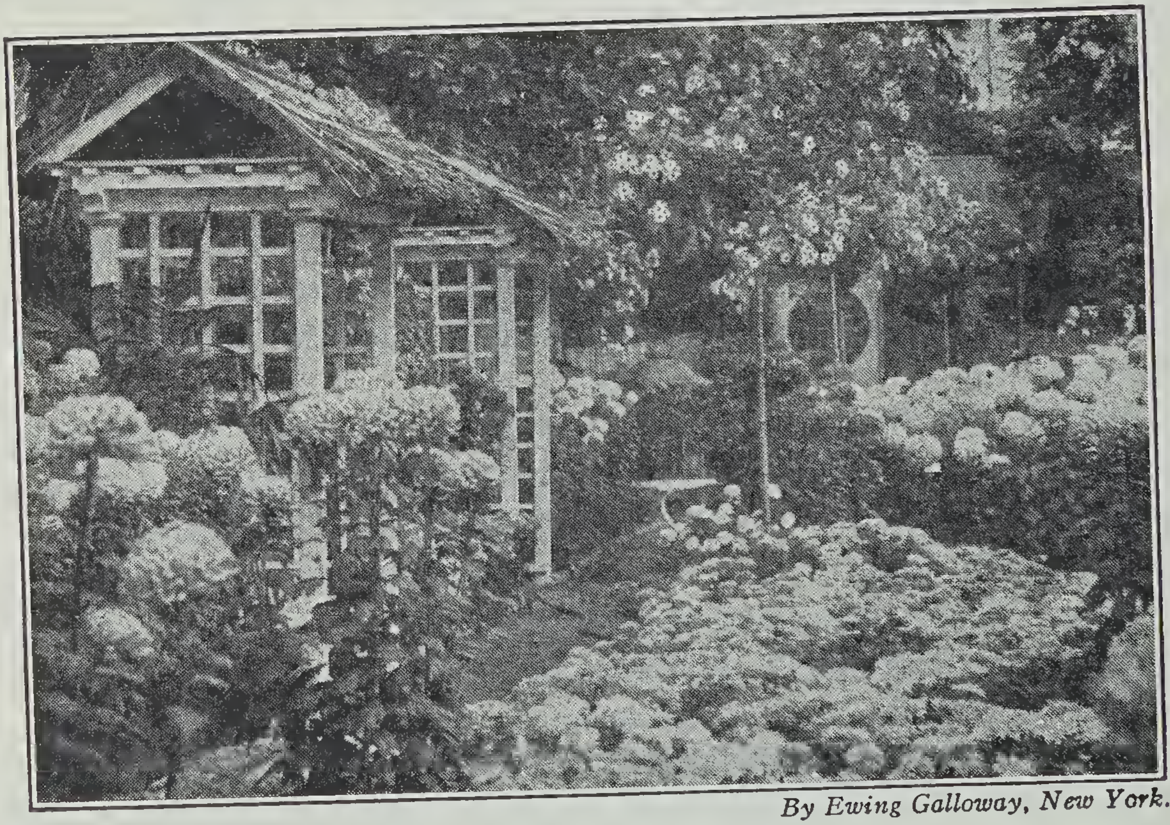
Parts of plants used for food. An interesting study could be made of the distribution of stored food in plants. Man selects for his own use the parts of plants in which food has been stored, either temporarily or permanently. Almost every part of plants is used as food, but not every part of any one plant.

Roots are represented by carrots, parsnips, turnips, and beets; stems by asparagus and bamboo; leaves by lettuce, spinach, and parsley; buds by lettuce, cabbage, and Brussels sprouts; flowers by cauliflower. The potato is really an underground stem (tuber), in which the "eyes" are buds. The peanut is a fruit, which grows underground after pollination of the flower. Probably the most extensively used parts of plants are the seeds. Peas and beans are seeds, and the cereal grains are one-seeded fruits in which the seed is the important part.

Next in importance to the seeds and roots are the whole fruits, such as apples, pears, oranges, lemons, pumpkins, tomatoes, watermelons, and bananas. Anyone who looks into the matter soon finds among plants some amazingly curious adaptations for storing food.

Plants and the atmosphere. Some of the most far-reaching contributions of plants to human welfare are made without man's seeking. One of these is involved in the relation of plants to the air. Since plants return to the air more oxygen than they consume, man profits. Plants take from the air more carbon dioxide than they return to the air, which no doubt tends to prevent accumulation of carbon dioxide in the atmosphere. Plants, by transpiration, are constantly returning moisture to the air. The evaporation of the water from the leaves absorbs heat from the air, thus making the air cooler, and at the same time more damp. Regions of forests often are cooler and more comfortable than barren regions in the same latitude or altitude. Rainfall is not only a factor in the growth of forests, but also the regulation of rainfall is in part due to the presence of forests. The moisture-laden air over great forest areas forms clouds, which in turn produce rain when they meet cold currents of air.

Floods and forests. Man has learned tardily, but perhaps not too late, that the presence of forests tends to prevent floods. We have noted that forests grow in regions of abundant rainfall. If you look at a map of the United States, you will see that the regions of great annual rainfall and the regions of forests nearly coincide. Rivers often have their sources in forested areas. In some of these places the forests have been cut away. Now the rain water falls on a barren land. When the flow of this water is not retarded by the presence of vegetation, or when the water is not absorbed by roots, it runs off so rapidly that floods occur in the valleys. The old stream beds cannot hold the great volumes of water rushing down at one time.



By Ewing Galloway, New York.

FIGURE 196. A flower garden.

Beauty. The value of plants cannot be measured in dollars and cents alone. We enjoy the presence of flowers and shrubs, forests and parks, green lawns, and waving fields of grain. Lawns, parks, and flower gardens cost money, but add greatly to our satisfaction, and the enjoyment of leisure time.

Clothing. Much of our clothing comes from plant sources. For many years cotton has been the basic textile material of the world. Rayon, a substitute for silk, can be made from cotton fibers, although fibers of spruce wood are customarily used. About 13,000,000 bales of cotton each weighing 500 pounds are produced annually in the United States. Linen is another plant fabric derived from flax. Jute, hemp, raffia, and straw are additional plant products.

Pulpwood. Ground-up wood from which we obtain cellulose is called pulpwood. The fabric called "celanese" is made from such material. The new nylon, however, comes from coal, air, and water. To some extent pulpwood trees are tending to replace the cotton plant as sources of commercial fibers. This fact suggests that in the future there will be greater demand for pulpwood, and correspondingly less for cotton.

In the past, most pulpwood has been utilized in paper manufacture. Logs are chopped up, and chemically treated to wash out gums, resins, and lignin. What is left is almost pure cellulose, similar to the substance of cotton and linen. When this material is spread out and rolled into thin sheets, it becomes the paper of commerce. Growing demands have led to the raising of pulpwood trees as a necessary and profitable enterprise. It seems that we shall have crops of trees, as well as of other things.

Lumber. Wood has always been our chief building material, though in modern times the use of steel, concrete, brick, and stone has increased. We use lumber to build houses and other structures, and also to make much of the furniture that goes into them. Thus hemlock, pine, and spruce boards are used in making frame buildings. Maple and oak often serve as flooring. Oak, maple, walnut, mahogany, and cherry are furniture woods.

In our day, certain trees have become scarcer. Reforestation and lumbering operations which save young trees are measures that tend to conserve valuable supplies of wood. It must be remembered that all trees are not equally useful as lumber. Thus it is possible to have trees in abundance and yet face a real shortage of some building materials.

Plywood. Plywood is a substance that has become very important in the past few years. It is estimated that the annual value of plywood made in this country is about $100,000,000. In the Pacific Northwest, Douglas fir logs are used in making this material. Logs from various hardwood trees are employed in other localities. The logs are peeled, and then put in lathes, which cut off thin sheets of wood. Such sheets are placed one upon another, with the grain of the wood in each succeeding section at right angles to that of the one just below it. An adhesive material is placed between the sheets (or the sheets may be dipped in the glue). Then pressure is applied to weld the slices of wood and glue into one solid whole.

Glues now used in making plywood come largely from soybean meal. Other adhesives can be employed, but most of them are more expensive. Modern plywood, when properly made, is light, very rigid, resists shock well, does not decay readily, and is largely waterproof. It is used in building airplane parts, cabinets, cases of various kinds, and many of the articles or permanent fixtures that go into homes.

Other plant products. Rubber is made from latex, the juice of the rubber tree (Hevea brasiliensis). Rubber trees are native to the American tropics, and some of our latex comes from this area. Most of the world latex supply, however, is now produced in the British East Indies. Recently, more or less successful efforts have been made to develop chemical substitutes for rubber.

Many other things that we use come from plants. Some of them are coffee, cocoa, tea, dried fruits, various drugs, plant oils, dyes, adhesives and plastics, spices, and substances used in tanning leathers. Plants that yield such materials are in some cases cultivated. Others are found growing "wild" in fields and forests.

Climate and plant industries. We have called attention to the change in crops seen when one passes rapidly over the United

States from north to south. There are nine regions in North America which are marked by special plant populations. The industries of these regions naturally are closely related to these plant types. The plants which succeed in any region must be adapted to the soil, and to the climate. Some of these are species introduced by man. Others are native species.

1. The Arctic region of Alaska, Greenland, and northern Canada, sometimes called the "tundra," is characterized by scanty vegetation.
2. The northern evergreen forests of Canada and of the states along the St. Lawrence River system, including the Great Lakes region, have been, since the early history of our country, centers of the great lumbering industries.
3. The southern pine region has been exploited more recently. Turpentine, longleaf pine, and cypress are characteristic products. Cotton comes from this same region.
4. The northwestern forests of the Oregon and Washington region form another great natural lumbering center. Forests grow in regions of abundant rainfall. This region is in the path of the moisture-laden winds from the Pacific. Rain occurs when the clouds reach the mountains. The great sequoias of California are within this general area.
5. The hardwood forests (or deciduous forests) are associated with the Appalachian Mountain system. Here, forestry has not been the main industry. Mining, manufacturing, agriculture, and trade have been important industries.
6. Florida, Central America, the West Indies, and Mexico make up a region in which tropical and semitropical forests thrive. The forest products are not the chief plant products. Cultivated plants, such as sugar cane, cotton, spices, fruits, chicle, and rubber, are important.
7. The great plains of the rising land west of the Missouri River have been notable as grazing lands for cattle, and as centers for the production of some cereal grains.
8. The prairie lands of the central part of the United States produce most of our cereals. Wheat, corn, and barley are most prominent. The flour-milling industries and meat-

Acme.

FIGURE 197. Apple trees in blossom (State of Washington).

packing houses are located in the cities of this region. The states of Minnesota, Iowa, Missouri, North and South Dakota, Kansas, Nebraska, Illinois, Indiana, and Ohio may be mentioned as occupying the prairie region. Fertile soil, moderate rainfall, and abundant sunshine during a sufficiently long growing season are conditions favorable to the growth of crops. Spring wheat is grown in the northern section, while winter wheat and corn are the chief crops of the belt running eastward from Kansas to Ohio.

9. The desert region of the southwestern part of the United States has less abundant natural vegetation. In recent years, however, irrigation has made it possible to grow many crops in this area. Cacti, and grasses adapted to dry climates, are native forms of plant life.

Useful bacteria. Some bacteria are undesirable, but there are other species which are beneficial. Some ways in which bacteria are useful to man are shown in the following list:

1. Many flavors in cheese and meat are produced by bacteria.
2. Some bacteria cause decay of dead organisms that are

thereby rendered soluble, and the materials of which they are composed are returned to the soil.

3. Some bacteria are found in the intestinal tracts of healthy animals. These "intestinal floras," as they are called, are believed by some physicians to serve a useful purpose.
4. Some bacteria attack other organisms which are undesirable.
5. Certain bacteria bring about the souring of milk, which is desirable for some purposes.
6. Some bacteria cause the souring of wine or cider, which represents the chemical change of alcohol into acetic acid. Vinegar is made by this action.
7. Bacterial action is involved in the making of pickles and sauerkraut, in curing of hides for leather, in retting of flax, in the storage of ensilage, and in the production of solvents such as butyl alcohol and acetone.

The nitrogen cycle. One of the most far-reaching contributions of certain bacteria to human life — indeed to all life — is their relation to the nitrogen cycle. "Nitrogen cycle" refers to the cycle of events by which nitrogen of the air passes into plants and animals, and then back into the air again. Nitrogen is one of the elements which is a part of protoplasm. Every plant and every animal requires nitrogen. It appears that no organisms, except certain bacteria, can use nitrogen in its "free" condition. All other living things can use nitrogen only in combined form; that is, in its compounds. Nitrates and ammonia are such compounds. Nitrogen of the air exists as an element. Hence the free and abundant nitrogen of the air is not directly useful in green-plant or animal metabolism.

The first process in the nitrogen cycle is the formation of nitrogen compounds by nitrogen-fixing bacteria, as discussed in Unit III. Such nitrogen compounds are absorbed by the roots of plants. Green plants make use of these nitrogen compounds in making proteins, a process which does not occur in the animal body. Proteins are organic compounds of nitrogen. Animals obtain proteins by eating plants, or by eating other animals, which in turn have eaten plants. These proteins are broken down into amino acids during digestion. The amino acids are taken in by animal cells and recombined to form the proteins of cell structures. Such cell structures may be oxidized, and protein wastes (containing nitrogen), such as urea, discharged from the body. The nitrogen wastes of animals eventually return to the soil or water. Then some of the nitrogen compounds are dissolved and again made available for absorption by plants.

When plants and animals die, the decay of their bodies is hastened by the action of bacteria. The process consists of breaking down the complex proteins into simpler nitrogen compounds, such as ammonia. These simple compounds become dissolved in soil water and thus are available for plants in the same way that the excretions of animals are available. Some bacteria appear to carry the process of breaking down the nitrogen compounds to the extreme. They actually decompose the nitrogen compounds. The element nitrogen is set free and returned to the air. This completes the nitrogen cycle.

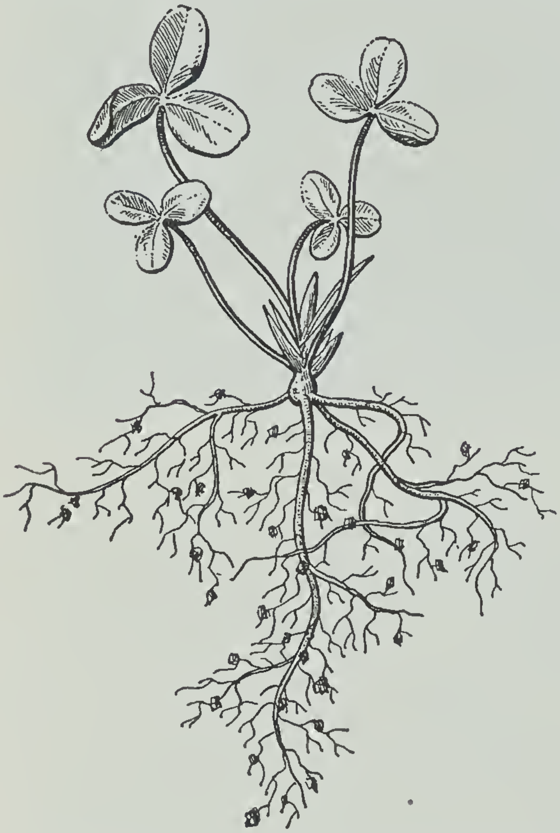


FIGURE 198. Diagram showing nodules of nitrogen-fixing bacteria on the roots of clover.

We may note that the following types of bacteria are involved in the nitrogen cycle:

1. Nitrogen-fixing bacteria, which cause free nitrogen to combine with other elements to form compounds.
2. Nitrifying bacteria, which (*a*) change ammonia into nitrites (nitrite bacteria), and (*b*) change nitrites into nitrates (nitrate bacteria).
3. Bacteria of decay (many mixed types), which break down complex proteins into ammonia or nitrogen gas.

Ammonifying bacteria form ammonia from various nitrogen compounds. The nitrogen-freeing bacteria decompose nitrogen compounds so as to liberate the nitrogen.

Useful fungi. We previously have learned that a number of other fungi are useful to man. Yeasts, for instance, may be responsible for fermentation. Some molds impart to food flavors which appeal to the tastes of certain people. Some fungi, including molds, hasten the breaking-down of organic matter in decay. Some mushrooms are used as human food, but other species are poisonous.

Summary. From the foregoing discussion we can see that plants affect human welfare in a variety of ways. In the case of the nitrogen cycle, man neither controls nor directs the process to any extent, but he has learned to use many plants to his advantage. From them he obtains materials for food, shelter, and clothing. The chief economic divisions of the United States are related to the floras found in these areas. Many species of plants are useful to man. It may be predicted that as time goes on, other species will be used to provide the materials of modern civilization.

SUGGESTED ACTIVITIES

Scientific methods

> A scientist uses scientific terms when they express ideas more precisely than do common terms. He does not use "big words" in an effort to impress people with his knowledge.

1. Make a collection of cereals and prepare them for display in the classroom.
2. Obtain as many commercial plant foods as possible. Arrange these for exhibit, and study in each case the portions of the plant (stems, roots, seeds, fruit, etc.) that are used as food.
3. After consulting the reading references at the end of this chapter, prepare a report upon one of the following industries: (*a*) rubber, (*b*) sugar, or (*c*) turpentine.
4. After consulting the reading references at the end of this chapter (including an encyclopedia), prepare a comparative report upon plant products. Compare the production and consumption of these products in various countries of the world, including the United States.
5. Prepare a wall chart which indicates the important raw materials derived from plants. Include sources of foods, clothing, dyes, gums, paper, tannin, medicinals, fibers, and various extractives.

6. After consulting the reading references at the end of this chapter, report upon some species of plants which have medicinal uses.
7. Prepare a map of the United States upon which are indicated the important crop areas and the large industrial centers. Is there any apparent relationship?
8. If opportunities for observation are available, make field trips and report upon such features as forested areas, deforested areas, orchards, sugar camps, reforestation projects, forest fires, farm crops, and water-supply systems.
9. Collect specimens of a large number of common woods (branches). Cut them to uniform lengths, and in such a manner as to expose cross sections and longitudinal sections. Examine the annual rings, bark, and other features of structure (see page 179). The exhibits should be accurately labeled.
10. After reference to page 461 and other sources, prepare a wall chart illustrating the nitrogen cycle.
11. Investigate, by reference to some books on agriculture, the relationships of humus, manure, sodium nitrate, "clover crops," and "crop rotation" to the soil. Prepare a report upon "Supplying Crop Plants with Food," in which you explain the importance of the above factors.

SUMMARY OF PRINCIPLES

1. Plants serve man as sources of food, shelter, and clothing.
2. The atmosphere, rainfall, and floods are affected by the presence or absence of plants.
3. Plants have value because of their beauty.
4. Rubber, paper, and other products are derived from plants.
5. There are nine notable regions of plant life in North America.
6. The nitrogen cycle is an important relationship involving the lives of green plants, bacteria, and animals.
7. Bacteria and (other) fungi help maintain the balance of nature by restoring the chemical constituents of dead organisms to the soil.

GUIDE QUESTIONS

1. Discuss twenty foods obtained from plants and indicate what part or parts of the plant are used in each case.
2. What is the function of stored food in a plant? Illustrate how man takes advantage of this stored food.
3. Discuss the plants involved in the production of sugar.
4. Discuss the relationships of forests to: (*a*) rainfall, (*b*) floods, (*c*) air temperature.

5. Discuss five woods used for lumber.
6. Discuss the production of rubber and paper.
7. What medicines are obtained from plant sources?
8. Discuss the nine "plant regions" of North America. Name an industry of each region.
9. Discuss seven favorable contributions of bacteria to human life.
10. What is the meaning of the expression "nitrogen cycle"?
11. Outline the steps in the nitrogen cycle and discuss the bacteria involved in any of these steps.
12. Discuss two beneficial fungi.

BOOKS TO READ

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De Kruif, Paul. *Hunger Fighters.*
Mavor, J. W. *General Biology.*
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Robbins, W. W., and Ramaley, F. *Plants Useful to Man.*
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Smith, G. M., and others. *Textbook of General Botany.*

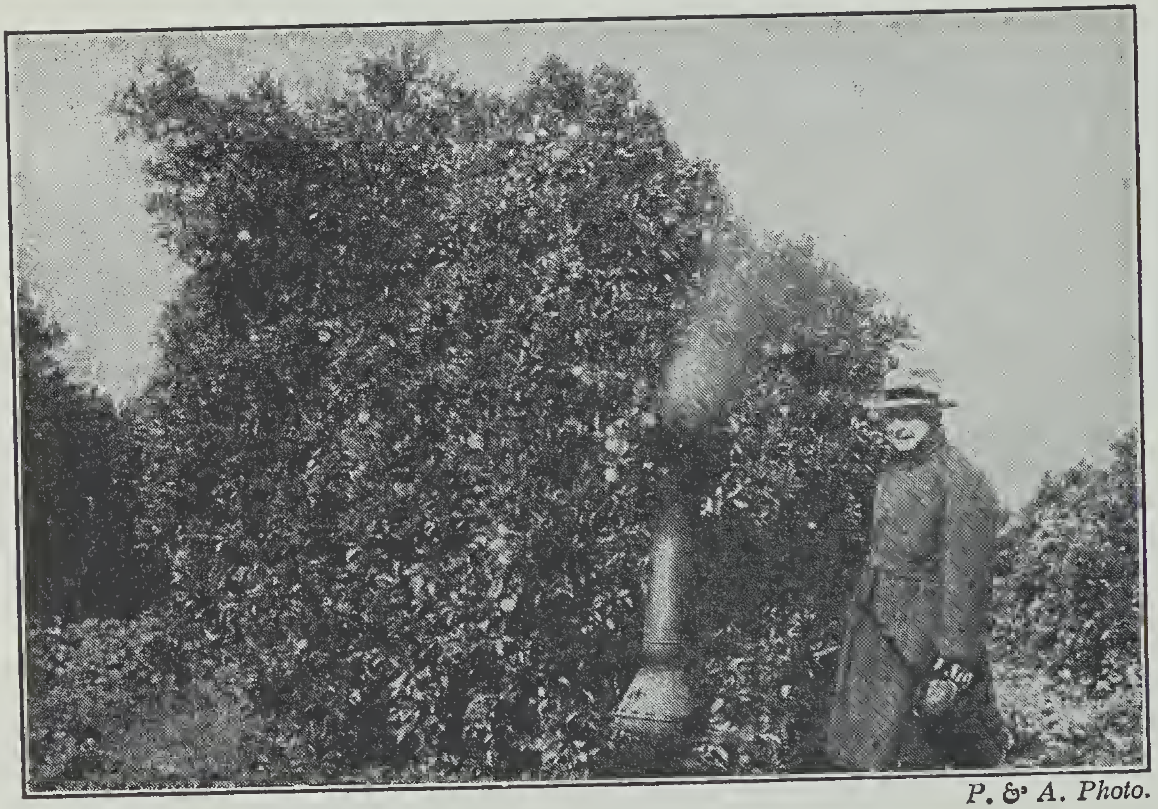
CHAPTER XXX

THE CONTROL OF PLANTS

Problems:

1. How have cultivated plants been developed from "wild" varieties?.
2. What is meant by "conservation"?
3. How are weeds controlled?
4. How is food spoilage by bacteria controlled?

Foreword. In the preceding chapter we have learned some of the ways in which man makes use of, or derives benefit from plants. Primitive man accepted plants as he found them in nature. Modern man, however, cultivates the more desirable species of plants. He also attempts to reduce the number of species which are undesirable. These two problems will be the subjects of the following discussion.



P. & A. Photo.

FIGURE 199. Using smudge pots to protect an orchard from frost.

By Ewing Galloway, New York.

FIGURE 200. Date palms growing in California.

MAN DEVELOPS INCREASING CONTROL OVER PLANTS

Improvement by protection. Man began to use certain plants very early in his social development. He has steadily improved them, and has taken measures to control their competitors. Historically, improvement started when man brought plants into his dooryard and protected them. The following factors are involved in the cultivation of plants by man:

1. Competition with rivals, both plants and animals, is avoided.
2. Additional food is supplied, and cultivated plants grow to larger size and give greater yields. For example, manure and artificial fertilizer are used to supply food materials for crop plants.
3. Water is supplied in any season, or in regions where the normal supply is insufficient. Sprinkling gardens and lawns, and irrigation of desert regions are well-known illustrations.
4. Nurture and protection of seedlings result in good root systems, and an earlier growth. Gardeners start tomato

plants, cabbages, lettuce, and many flowers under glass early in the spring. When danger of frost is over, these young plants are transplanted into gardens.

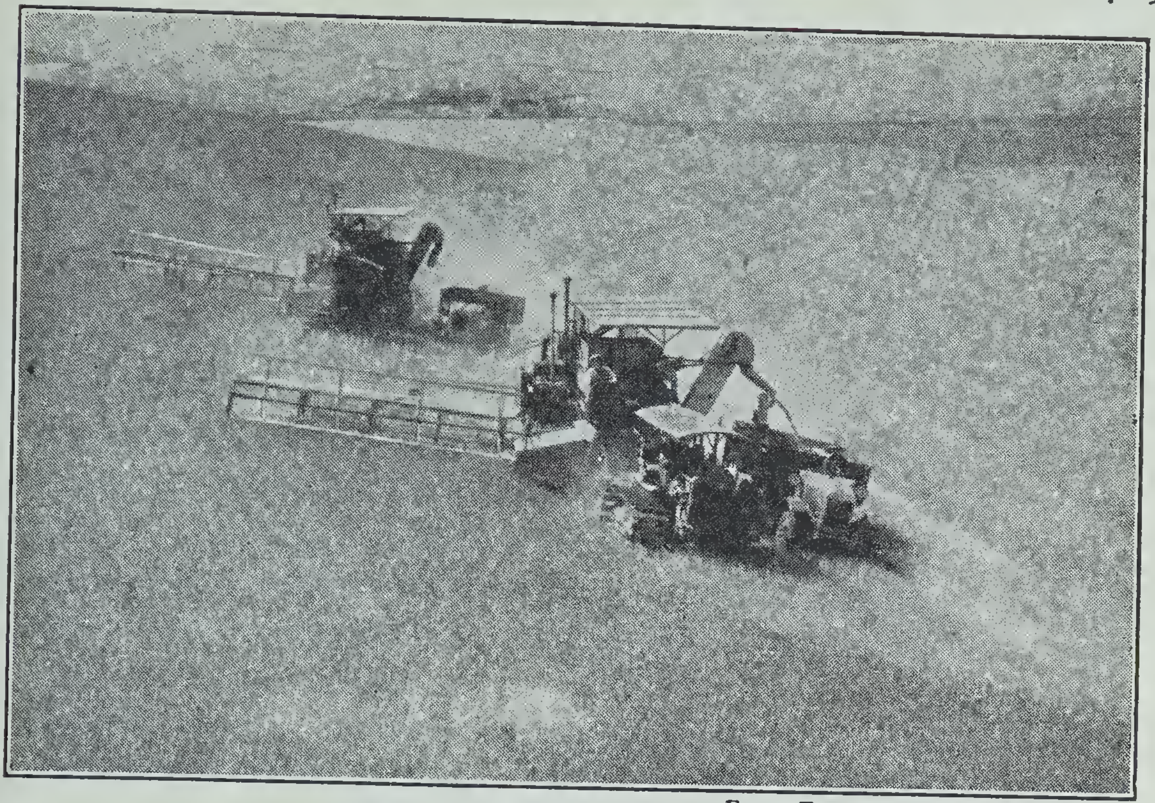
5. Cultivated plants are protected from their natural enemies and competitors. For example, fungi may be killed by spraying, and potato beetles removed, or killed by poisons. Weeds are destroyed by mechanical or chemical means.

Selection. Observation has convinced man that the best seedlings produce the best plants, and that the best seeds produce the best seedlings. In this we recognize the principle of variation. Every seed and every plant is a bit different from others. By selecting and using the types that possess the qualities desired, man has developed races of plants far superior to their ancestors. For example, if the largest kernels from the largest, best-filled ears of corn are used for seed the following year, improvement in the *average* quality of the corn crop might be expected to occur. This is called "mass selection."

Since the principles of Mendel's law have been extended to practical breeding, selection of individuals in the light of these principles is accepted as being more scientific than mass selection. Using Mendelian methods, a longer time usually is required to obtain a commercial supply of seeds. However, the desirable qualities can be more definitely assured in the final product.

Kanred wheat. An oft-quoted example of selection is afforded by Kanred wheat. The most important variety of winter wheat grown in the Kansas area prior to 1917 was the "Turkey." This variety was, however, very susceptible to black stem rust. The story is told that Professor Roberts of the Kansas State Agricultural College noticed a single stalk of wheat which showed no rust. It grew amid a large number of individuals of Turkey wheat which were badly infected. Professor Roberts saved this head of wheat and planted the seeds. Happily, the plants that grew from the seeds also resisted rust. These plants in turn produced seeds which continued to produce plants with the qualities of the original ancestor. Do you think this variety was a mutant or a hybrid?

Whatever you decide about this question, the facts are that



From Ewing Galloway, New York.

FIGURE 201. Combines being used to harvest wheat in Washington. These machines cut and thresh the grain.

eventually enough seed was produced to distribute to the farmers. Eleven years, from 1906 to 1917, were required by Professor Roberts to complete his experiments. But the results more than paid for the time and effort. Today, this wheat is probably the most successful and widely used winter wheat in the State of Kansas, for which it was named. In addition to its rust-resisting qualities, Kanred wheat yields an average of four and one half bushels per acre more than the previous best variety. Moreover, it withstands cold winters. This is a desirable quality in "winter" wheat, or wheat that is sown in the fall. It is estimated that the State of Kansas profits annually from this discovery by as much as twenty millions of dollars.

Hybridization. Another method of breeding is to attempt to bring about desired qualities by fertilizing the egg cell of one variety with the sperm cell of another. This method is called crossbreeding. The results cannot be predicted. Sometimes variations occur which are desirable and which "breed true." At other times variations may be useless, or may not be inherited. Frequently the variations are so slight that they are not significant. This method requires extreme care and control of pollination, and of other factors in the process. The result of crossing two related varieties is, of course, a hybrid. The principles of dominant and recessive characters are involved.

Marquis wheat. A variety of wheat also may serve to illustrate crossbreeding, and to show the economic importance of this method. In Canada and other regions where the growing season is short and the winters cold, wheat is sown in the spring, and must be able to mature before frost comes in the fall. Professor Charles Saunders, Director of Cereal Investigation for Canada, undertook the task of producing a variety of wheat to meet these conditions.

He collected wheat from all parts of the world — hundreds of varieties. He planted the seeds in special plots of ground and crossbred the plants for several years. From among the numerous offspring, a strain of wheat which bred true and which possessed the desired qualities eventually was selected. This variety was called "Marquis." The parent plants were (1) Red Fife, a hard spring wheat, and (2) a variety of hard, red, winter wheat from India. Marquis matures, on the average, in 115 days, about five days earlier than Fife, resists rust well, and withstands dry weather successfully. It is now the leading wheat grown in Canada, and is rapidly becoming the most important spring wheat of the United States.

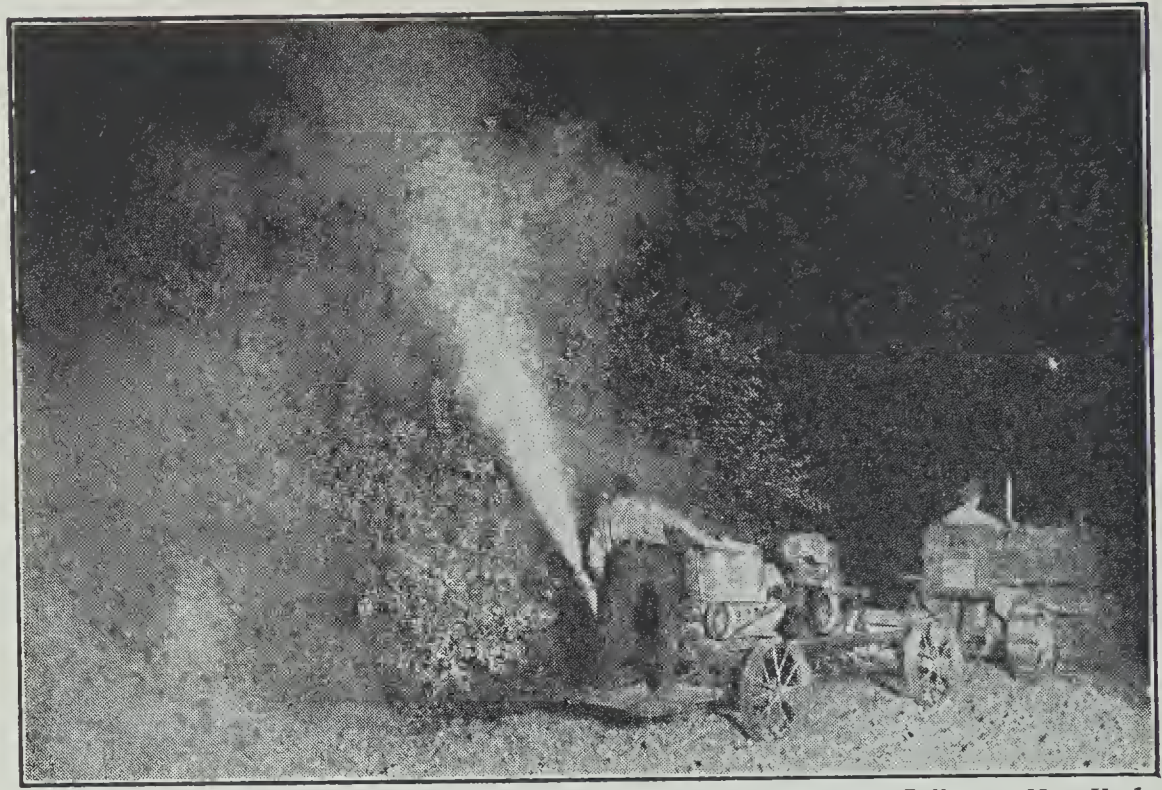
Concord grapes. Another example is afforded by the Concord grape. This is the most common and popular variety of grape grown in the Eastern grape-growing regions of the United States. It was developed by Ephraim Bull in 1853. He succeeded in crossing by pollination two species of wild grapes. From the seeds of the fruit thus produced, he grew over twenty thousand seedlings. *One plant* from this number was "selected" because of the large size of its fruit, accompanied by sweetness and other desirable qualities. This plant, by vegetative propagation and also by use of seeds, was caused to reproduce other plants. The result is the present valuable and delectable Concord grape.

Burbank. Luther Burbank was a master of the art of developing desirable plants by selection and crossing. Many improvements in plants with respect to yield of flowers and fruit, quantity of stored food, and other characteristics of economic importance, have resulted from his experimentation. The Burbank potato, Santa Rosa plum, giant prune, the plumcot — a cross between the plum and the apricot — and the Shasta daisy are among his valuable contributions. At the time of his death it is said that he had over 3000 experiments under way, with over 5000 plant species involved. It was his custom each year to raise more than a million plants for experimental purposes. In developing the "white blackberry" by crossing, he burned in one year as many as 50,000 blackberry plants which failed to show the qualities he desired.

Hybrid vigor. Hybrid vigor is a term applied to the fact that many hybrids have qualities of resistance or of size apparently not possessed by either of the parents. Hybridizing is seen as the opposite of "inbreeding," which is the continued reproduction by individuals of a single strain or variety.

Many factors are involved, but we may state the general principle that inbreeding may result in the continuance of desirable traits. Its bad repute results from the fact that any undesirable characters which are present in the stock may also be continued. Hybrid vigor involves principles that are not yet well understood. Practical gardeners, nurserymen, and animal breeders recognize it as a fact, and deliberately hybridize with the purpose of strengthening a strain. However, the results are not always as expected.

Vegetative propagation. Continuance of desired qualities may be attained, as we have seen (page 383), by the methods of vegetative reproduction. It should be recognized as one of the methods of improvement of plants. Probably most of our best fruits have been improved by a process of artificial selection and vegetative propagation.



From Ewing Galloway, New York.

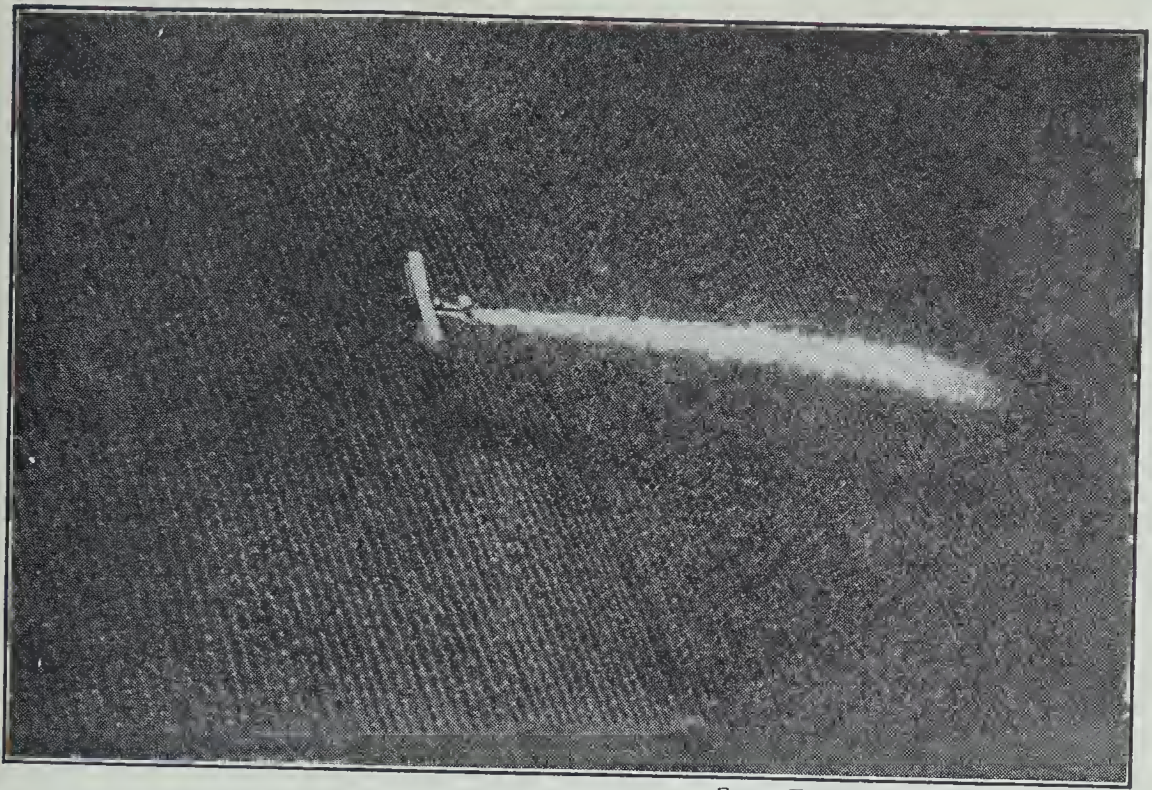
FIGURE 202. Dusting an apple orchard with lime dust — a means of biological control.

WE SHOULD PRESERVE NATURAL RESOURCES

Natural resources. In the preceding pages we have noted some ways in which man has improved plants. Such improvements have been very profitable. In some other respects, however, we have not been far-sighted. We have, for example, been wasteful of natural resources in North America.

Two centuries ago, the eastern part of North America was largely covered by primeval forests. The western prairies were succeeded still farther west by vast tracts of land covered with short grasses. There were many streams feeding into the larger rivers — streams that carried water throughout the year. Springs which brought water to the surface from underground sources kept the small streams running continually. Marshes, lakes, and ponds were to be found in many parts of the country.

In the rocks were valuable deposits of ores. Some of these ores were destined to yield iron, lead, copper, silver, gold, and



From Ewing Galloway, New York.

FIGURE 203. Using an airplane to spread poison dust over a cotton field — a method of controlling the cotton boll weevil.

other metals. Large tracts were underlain by coal deposits. Oil basins lay beneath several areas.

Soil. But of even greater importance was the soil. Soil is a mixture of materials that have been eroded (weathered) from the rocks, and materials that have come from the decay of plants and animals. The top soil in many parts of North America was very fertile. It would support an excellent growth of crop plants. Such a top soil had not been developed in a few years. It contained the remains of countless generations of plants which had lived, died, and had been returned to the soil.

Destruction of natural resources. The early settlers in the eastern region began the work of clearing away the forests. At that time this was necessary, in order that crops could be planted and food could be produced. As settlements were extended westward, more and more of the forests were cleared away, to be replaced by plowed fields. Wood was used for heating purposes, as building material, in making furniture, as paper pulp, and in many other ways.

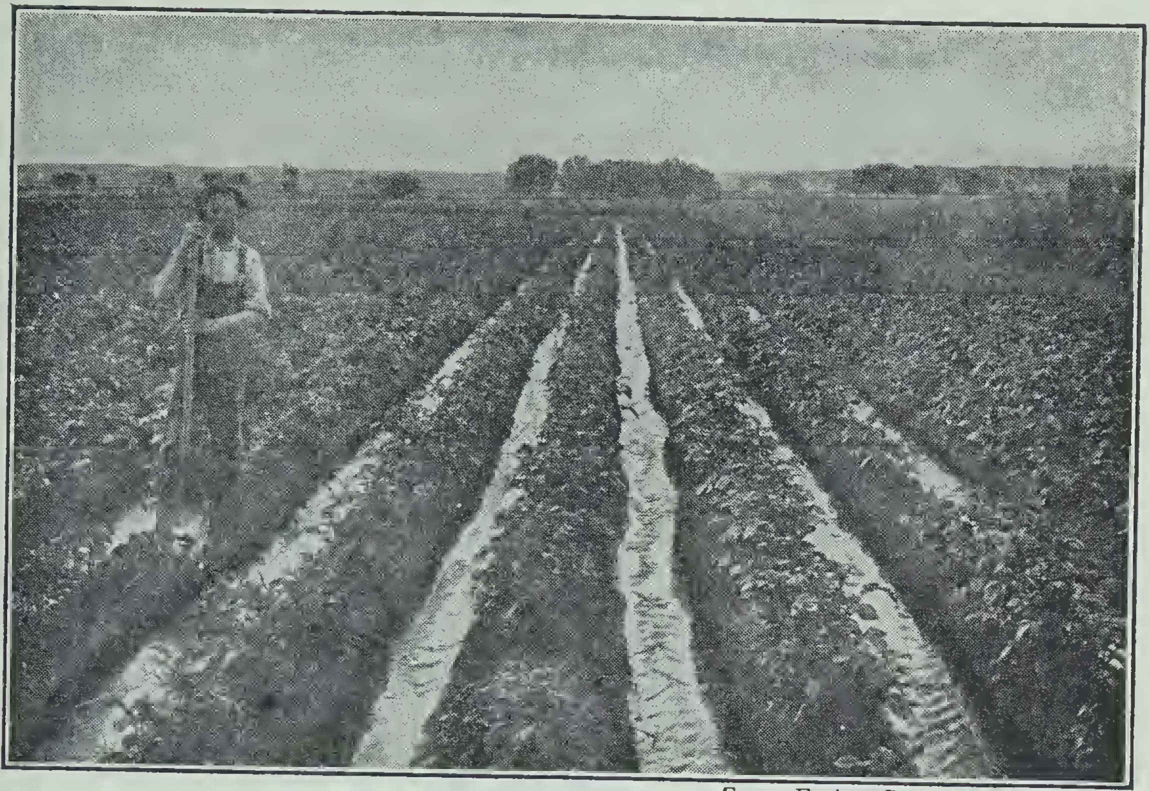
In the prairie regions at a somewhat later date, lakes and marshes were drained. In part this was done to remove breeding places of mosquitoes. But it was also done in order that more land could be broken by the plow. Timber lands along streams were cut away. Fields were drained through the use of ditches and tile so that they could be cultivated in wet seasons.

Still later in history cattle replaced the bison on the western plains. Then came the sheep. The latter ate down the short grasses to their roots, and their presence did much to destroy the natural vegetation. Finally large areas of the arid country were plowed and planted with wheat. When occasional wet seasons came, this wheat produced very satisfactory yields.

Erosion. But meanwhile various forces of nature had been at work. We have already learned that the presence of plant roots tends to hold the soil against erosion (see page 456). Where the eastern forests were cut away from the hillsides running water was able to carry the top soil down the streams, and eventually to the sea. Where grasses of the plains were destroyed by the sheep and the plow, wind erosion created great dust storms. The clouds of dust that have been carried across the western country represent the valuable top soil — soil that cannot be replaced in our generation.

Floods and Droughts. When periods of heavy rain came, the forests, marshes, and lakes were no longer there to hold the water. The water ran rapidly down the bare hillsides carrying top soil with it. In the valleys where the flow of water had once been checked by lakes and marshes, few lakes and marshes remained. In their places were ditches which hastened the flow of water into the streams. In many cases the result was flood and disaster.

But this was not the full extent of the damage. For in dry seasons the streams had shrunk to the vanishing point. Drainage had removed water from the soil. Springs had become dry. The soil itself was dry during the long summer months. It was no longer able to retain the moisture which came from the melting of winter snows and the spring rains. Crops began to fail because there was not enough soil moisture.



From Ewing Galloway, New York.

FIGURE 204. Irrigating a potato field in Colorado.

Conservation measures. Somewhat tardily we have begun to think of conservation measures. Great deposits of coal and pools of oil remain, and if used wisely will last for years to come. Much valuable top soil has been lost forever, and gully erosion has made many acres unfit for agricultural purposes. But valuable soil remains. Scientific agriculture will enable us to make the best use of this soil.

Saving the fertile top soil is largely a matter of preventing erosion. So we are now attempting to restore forests to the hillsides and grass to the plains. Even the best varieties of cultivated plants will be of little use to man unless a good soil is available for their growth.

Forest conservation. In recent years various areas of land have been set aside by the United States government and some of the states as forest reserves. Over one hundred and sixty million acres are now dedicated to such purposes. The United States Forest Service (Division of Forestry, Department of Agriculture) supervises these forests.

The forest service maintains fire patrols in many places. When a forest fire occurs, the wind-blown flames sweep all life before them. Many forest fires result from carelessness. The forest service also carries on reforestation work. Young trees are set out on government land. Land owners are encouraged to plant young trees on their property. The planting of these young trees will aid in preventing erosion, and will provide a valuable supply of timber in the future.

Conservation in general. Forest conservation alone will not solve our problems of erosion, floods, and droughts. Some of the lands of the plains region that are now broken by the plow should be returned to sod. The grass roots would then tend to prevent wind erosion. There is also the conservation of wild life. The bison, the beaver, and several other North American animals have been reduced in numbers to the vanishing point. Many native birds have become scarcer. Native fishes have disappeared from the streams. In part, this has been due to the activities of hunters and fishermen. But probably of greater importance has been the removal of natural habitats. Deforestation, drainage of lakes and marshes, destruction of grazing lands, and stream pollution have been the forces of destruction.

Biological control. In the past man has protected the plants and domesticated some animals that he could use. He has tried to destroy plants and animals that interfered with his success. Various types of organisms have been brought to North America from other parts of the world. In some cases this program has succeeded. In other cases it has failed.

The biological or scientific control of organisms is gradually replacing guesswork in this field. Facts are collected from all sources. The results of experiments furnish other facts. In the light of such facts one organism is sometimes introduced to destroy another organism. This is called *biological control* (see pp. 537, 569, and 578). Such measures should be adopted only after careful study. Too often has careless tampering with the balance in nature resulted in more harm than good. Haphazard destruction or thoughtless introduction of new species often results disastrously.

SOME PLANTS ARE INJURIOUS

Weeds. We must recognize, however, that some kinds of plants are clearly undesirable. Among these are weeds — plants in the wild state that man has not been able to utilize. Weeds might be defined as "plants growing where we do not want them to grow." If allowed to grow in a garden patch or on a lawn, weeds deprive the cultivated plants of nourishment, of sunlight, and of water.

Weeds often have adaptations which are superior to those of the plants we wish to raise. They will flourish where little else can be grown. This is because some weeds have such structures as long roots which reach down to moist soil. Or perhaps they have horny coverings or small leaf surfaces, and are able to retain water in dry weather. Weeds can best be controlled by cultivating the soil, and by destroying the weeds before they can produce seeds.

Hay fever. Pollen dust is the cause of some cases of "hay fever" and "rose cold." Noses and throats become irritated by reaction to certain pollens. Some people seem to be very susceptible to some pollens, but not to others. Other people appear to be immune to all pollen.

Undesirable bacteria. Various bacteria are useful to man. Others attack living organisms, including man. Some bacteria are the chief cause of food spoilage. Less than a hundred years ago the great French scientist, Louis Pasteur, began a study of wines. The souring of wines was costing French wine-makers thousands of dollars every year. He found that certain bacteria caused the souring. Eventually, this discovery led to other discoveries, relating bacteria to food spoilage, and to disease. Briefly stated, the various methods now used in preserving foods are:

1. *Drying.* Some fruits, meats, and vegetables resist the action of bacteria when they have been dried.
2. *Sealing and boiling.* This is the common canning practice. Foods are sealed in containers, and then heated to kill all bacteria.
3. *Freezing.* Fish and meats are sometimes frozen. The chief objection to ordinary freezing is that the cell walls of the food material are ruptured by the formation of large

crystals of ice. Recently, scientific study has developed a quick-freezing process which preserves some fresh foods without destroying the texture or flavor. It makes use of the well-known principle that the more rapidly crystallization takes place, the smaller are the crystals. Several methods have been devised in all of which the essential features are to freeze the food at temperatures from −20° to −40° F., so that only about forty minutes are required for complete freezing. The older methods of slow freezing required in the neighborhood of twenty-four hours.

After the quick-freezing treatment, the materials must be kept below the freezing point of water. This condition is satisfactorily maintained by use of "dry ice" (solid carbon dioxide). When the food is to be used, it may be soaked in cold water which restores it almost to its original form and flavor.

4. *Refrigerating.* If temperatures are kept low, but above freezing, foods are preserved without injury. Home refrigerators and refrigerating cars are indispensable to modern life. Bacterial action is not prevented, however; it is only retarded. Hence the method is effective only for short periods of time. The effectiveness varies according to the types of bacteria that are involved.
5. *Smoking and salting.* Meats and fish are preserved for long storage by thorough salting, or smoking, or both. Both salt and ingredients of smoke are chemical agents which check the action of bacteria.
6. *Sirups.* Some sugar solutions contain about one pound of sugar to a pound of water. Yeasts, molds, and bacteria do not readily reproduce in such sirups. Hence fruits are often preserved in these mediums.
7. *Chemicals.* Certain antiseptics, whose effects on the human body when used in small quantity are slight or debatable, sometimes are added to foodstuffs. Among these chemicals are salicylic acid, sodium benzoate, and sulphur dioxide. Although some of these are permitted, under certain restrictions, by the United States Pure Food and Drug Act, their use is not recommended.

FIGURE 205. A Civilian Conservation Corps Camp. (Courtesy of the New York State Conservation Department.)

8. *Vinegar and spices.* Preserving and pickling in vinegar, with or without spices, salt, or sugar, are common methods of keeping foods of all kinds. Modern sterilization and sealing are largely replacing these methods, except where the flavors of the pickling substances are desired.

Summary. In conclusion we may again note that man has always depended upon plants for food, shelter, and clothing. He has not been content to use plants as they grow in the wild state, but has selected for cultivation some of the more desirable types. These types have been improved under cultivation, through the application of biological principles. Man has learned that it is to his advantage to conserve natural resources, such as forests, and that any disturbing of the balance in nature may lead to unfortunate results. The control of undesirable plants, such as weeds and certain bacteria, is an established practice in modern life. This control is also based upon understanding of various biological facts. In the following discussion we shall consider the control of bacteria and other organisms which are associated with disease.

SUGGESTED ACTIVITIES

Scientific methods

A scientist often repeats the experiments of others, both to verify their results, and to learn new facts.

1. Prepare an exhibit showing the results of plant cultivation. Compare, for example, wild and cultivated cherries, raspberries, grapes, or other types.
2. Illustrate improvement through selection by using large and small kernels from the same ear of corn. Germinate twenty large kernels and twenty small kernels under similar conditions. Compare the rates of germination, height of seedlings at various times, their root systems, and other characters.
3. Read *New Creatures in Plant Life*, by W. S. Harwood (Macmillan, 1918). Report upon some of the work of Luther Burbank.
4. Read *The Apple Tree*, by L. H. Bailey (Macmillan, 1932), and learn how to make a "graft." Bring a branch of a tree to class and demonstrate a method in grafting.
5. Collect and mount, with suitable labels, a number of weeds or weed seeds. Report upon undesirable qualities of the various species and the methods used in their control.
6. Collect examples of plants which have been attacked by diseases or insect enemies. Mount them in display form, indicating the type and cause of injury in each case.
7. On a sheet of paper write numbers from 1 to 10, and indicate after each number whether or not the following statement correspondingly numbered is true or false. Explain in each case.
    1. Cultivated plants are always better adapted to their environments than are weeds.
    2. Kanred wheat resists infection by black stem rust.
    3. Hybridization was involved in production of the Concord grape.
    4. Inbreeding always results in the conservation of desirable traits, and the elimination of undesirable traits.
    5. Man's use of forests always has been scientific.
    6. The suppression of undesirable species should be guided by the results of biological experiments.
    7. The introduction of new species is always desirable.
    8. Weeds often flourish where many cultivated plants do not grow successfully.
    9. All bacteria are enemies or competitors of man.
    10. Freezing of foods is the most satisfactory method of preservation.

SUMMARY OF PRINCIPLES

1. Many species of plants have been cultivated by man; improved varieties have been developed through selection and hybridization.
2. Removal of forests and destruction of grasslands are related to soil erosion. We can and should preserve natural resources.
3. Careless destruction of wild life, or introduction of new species, may lead to unfortunate results.
4. Undesirable plants, such as weeds and some bacteria which are associated with the decay of foods, can be controlled in various ways.

GUIDE QUESTIONS

1. Discuss ways in which man provides advantages for cultivated plants.
2. Discuss "mass selection" and the production of desirable varieties by this method.
3. Discuss the biological principles involved in the production of Kanred and Marquis wheat.
4. For what kind of biological work is Burbank noted?
5. What is meant by "hybridizing," and "hybrid vigor"?
6. Discuss methods involved in the conservation of forests.
7. What is meant by the expression "scientific agriculture"?
8. What are some of the methods employed in controlling weeds?
9. In what way may hay fever be related to plant life?
10. What are some of the methods employed in controlling bacteria whic are associated with the decay of foods?

BOOKS TO READ

Chase, Stuart. *Rich Land, Poor Land.*
Coulter, J. G. *Plant Life and Plant Uses.*
De Kruif, Paul. *Hunger Fighters.*
Fitzpatrick, F. L. *The Control of Organisms.*
Palmer, E. L. *Conservation.* Cornell Rural School Leaflet, vol. XXIX, no. 3.
Parkins, A. E., and Whitaker, J. R. *Our Natural Resources and Their Conservation.*
Sears, Paul. *Deserts on the March.*
Smith, J. B. *Men and Resources.*
Whitney, M. *Soil and Civilization.*

Chapter XXXI

THE GERM THEORY OF DISEASE

Problems:

1. What are "germs"?
2. What are "epidemic diseases," and what is meant by "preventive medicine"?
3. What diseases have germ origins?
4. What are the natural defenses of the human body against germs? How may these defenses be strengthened?
5. What are some measures in public sanitation?

Foreword. The small parasites which attack man are among his most dangerous natural enemies. The presence of certain of these small organisms in the human body may result in various infectious diseases. Sometimes these minute organisms are called microbes, and sometimes they are called germs. The germ theory of disease holds that infectious diseases are produced by specific germs or microbes. With reference to some of the most dangerous infectious diseases this is no longer a theory, but a demonstrated fact. Many, but not all infectious diseases, are easily communicated from one person to another. The method of communication varies in different cases. Such diseases are known as "communicable diseases."

A good many germs are to be found among the bacteria. Some of the protozoa might also be called germs. Another group of germs is found among the simple organisms known as spirochætes.[1]

GERM DISEASES HAVE BEEN COMMON FOR CENTURIES

Epidemic diseases. An epidemic disease is a communicable disease which becomes widespread in a region. Usually an epidemic begins gradually, reaches a climax, and then subsides.

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[1] Sometimes classified as protozoa.

After another interval of time this same disease may reappear in the region in epidemic form. Sometimes a disease is peculiar to a given area. Fewer people are affected at one time, but the disease is always present. In the latter case the disease is said to be endemic in the region.

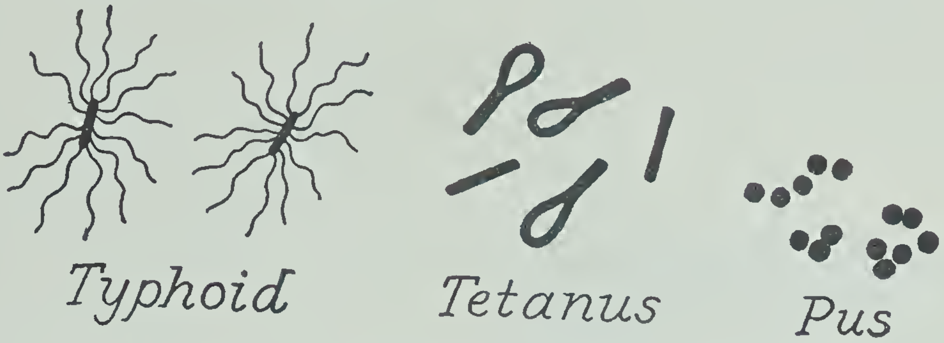


FIGURE 206. Types of germs (bacteria). Could the diseases represented here be inherited?

Bubonic plague. Bubonic plague is a disease which appears to be endemic in some parts of the world, especially in parts of the Orient. At different times during the history of human civilization it has become epidemic in Europe, and even in parts of North America. Rome suffered an invasion of bubonic plague in A.D. 68. Another epidemic began in A.D. 164; this one lasted for sixteen years. At the height of the second epidemic it is estimated that about ten thousand people died every day. Other germ diseases were common in Rome. In this group such diseases as malaria, diphtheria, typhoid fever, leprosy, and tuberculosis appear to have been included.

Health conditions during the Middle Ages. Health conditions were very bad during the days of the Roman Empire, but they probably were even worse during the Middle Ages. England was visited by the bubonic plague at different times during the fifteenth, sixteenth, and seventeenth centuries. Thousands of people died during the courses of these epidemics. Other diseases, such as those mentioned above, were common in all of Europe. One reason for the existence of such conditions was the general lack of knowledge concerning the causes of disease.

Superstitions about diseases. Before and during the Middle Ages, and down to comparatively modern times, epidemic diseases were more or less of a mystery, and superstitions were substituted for accurate knowledge. The appearances of such natural phenomena as earthquakes, comets, and eclipses were supposed to foretell the coming of plagues (epidemics.) These plagues were supposed to be visitations of Providence, and to serve as punishment for sins.

Various charms were worn by many people, in the belief that they would protect the wearers from diseases. Sacrifices were offered in an attempt to appease an angry Providence. When plagues did come, certain people were suspected of being responsible. In a vague way they were thought to be in league with the devil. In many cases these innocent people were tortured in an attempt to wring confessions from them. If they confessed, they were killed; if they did not confess, they usually were killed anyway, or died as a result of the torturing they had undergone.

In our modern times it is interesting to note that we are not entirely free from the superstitions that have come down to us from the past. There are still people who wear charms, and apparently believe in their potency. Precious coral is worn in parts of Europe in the belief that it will ward off the "evil eye."

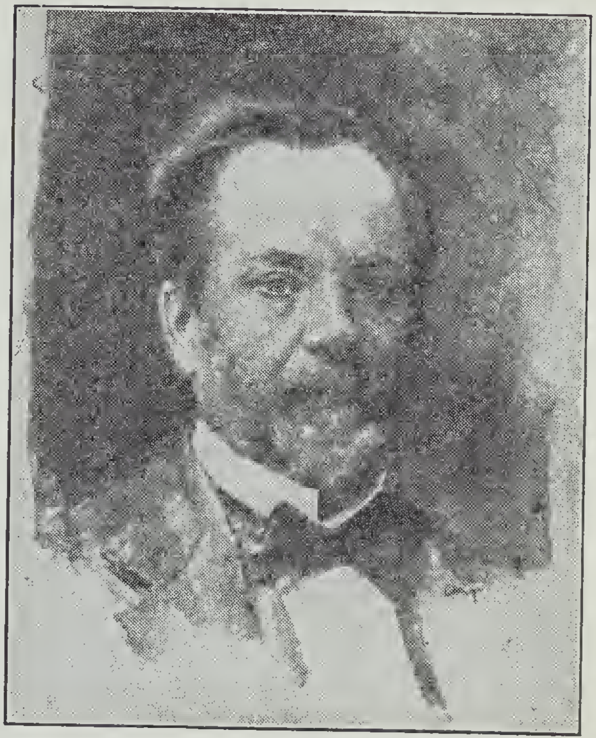
Average length of life. Three centuries ago the average human life lasted about twenty years. Some individuals lived much longer, but on the other hand, many died in infancy. Today, the average span of life of white races is over fifty years. The increase is largely due to better care of children. Fewer individuals die in infancy. The so-called "long-lived" people probably do not live any longer than they did three centuries ago. The great mass of human population is much better protected against the diseases that result in death during infancy.

Preventive medicine. It is well to remember that modern civilization is dependent upon preventive medicine, so called because modern physicians attempt to prevent the disease as well as to cure it. We need only reflect upon the terrors of the plague days in Rome, London, and other European cities, to realize what might happen to the people in some of our crowded modern cities if preventive medicine were not constantly guard-ing their lives. In fact, it is a very apt question whether or not the large city of today could continue to exist were it not for modern knowledge of epidemic diseases. Nor would life in rural districts be as safe as it has become in many places.

THE INVESTIGATIONS OF PASTEUR, LISTER, AND OTHERS ESTABLISHED THE GERM CONCEPT OF DISEASE

The Greek philosophers suggested that diseases might be caused by minute organisms in the human body. Writers of the Middle Ages renewed this suggestion. No experiments were performed in an effort to test the hypothesis, however, until the nineteenth century, when the works of Pasteur, Lister, and others established the germ concept of disease upon a scientific basis.

Pasteur. Louis Pasteur, a Frenchman, lived in comparatively modern times, dying in 1895. His first investigations have been discussed previously. In the course of these studies he found bacteria in spoiled and bitter wines, and demonstrated that these bacteria could be killed by heating them.



American Museum of Natural History, New York.

FIGURE 207. Louis Pasteur. A famous French scientist who was born in 1822, and died in 1895. Pasteur achieved fame through his studies of small organisms — mainly bacteria. He demonstrated that spontaneous generation does not occur. His studies of disease-producing organisms have been of the greatest importance to civilization.

Chicken cholera. In 1875 Pasteur began his study of cholera in chickens and anthrax in sheep. He was able to isolate the germs (bacteria) of cholera and raise them in a culture. The culture consisted of a group of cholera organisms in a broth. He found that after a period of time all of the cholera organisms in a culture would die. The reason for this was that they multiplied very rapidly, and soon became so numerous that they were poisoned and killed by their own waste products. Then Pasteur found that he could keep his living cholera organisms indefinitely if he started new cultures occasionally by transferring a few cholera bacteria from an old culture to a new dish of broth.

Pasteur fed bits of active cholera culture on pieces of bread to chickens. The chickens always developed the symptoms of cholera and died. This indicated the relationship between the cholera organisms, which up to this time were only suspected of producing cholera, and the development of the disease.

Then Pasteur fed some old cholera culture to chickens. The bacteria in this old culture presumably had been poisoned to the extent that they could not reproduce. The chickens became sick, but after a few days they recovered. Pasteur now fed active cholera culture to these chickens and they did not develop the symptoms of the disease. Thus a method of conferring immunity to chicken cholera was discovered.

Anthrax. Pasteur was equally successful in his study of anthrax in sheep. As in the case of chicken cholera, he was able to develop a vaccine which protected the sheep against anthrax. Pasteur's work was questioned and he prepared a public demonstration as a test. Twenty-five sheep were given doses of anthrax vaccine. Fifteen days later these same sheep were given doses of anthrax vaccine once more. Meanwhile, twenty-five sheep in another group received no vaccine. After a period of two weeks all fifty sheep were given the active bacilli of anthrax. Two days later the twenty-five sheep that had been inoculated with the vaccine were alive; the twenty-five sheep that had not been thus protected were dead.

Rabies. Pasteur also made a study of rabies or hydrophobia. This is a disease of cats, dogs, other animals, and man. Pasteur did not succeed in isolating any organisms of rabies, nor was he able to proceed with the work by the same methods he had used in the cases of chicken cholera and anthrax. The supposed organism apparently grew in the nervous tissues of animals having the disease. Pasteur removed the spinal cords from such animals and dried them. Probably the drying weakened or killed the supposed organisms, or the virus (poison) of rabies. The dried spinal cords were then pulverized and the material was injected into rabbits. These rabbits now became immune; in other words they would not develop the disease. Later, it was found that immunity by the so-called Pasteur treatment can be conferred in about a week. It requires some three weeks for rabies to develop after an animal has been bitten by a dog having rabies, or any other rabid animal. Treatment may be successful even though it *follows by several days* the bite of the rabid animal. This is a case in which successful treatment is available, even though no germ has been proved to cause the disease.

Lister. Sir Joseph Lister, an Englishman, was graduated from the University of London in 1852 and became Professor of Surgery in the University of Glasgow in 1860. Lister began his work at a time when pus, a white fluid resulting from infection in wounds, was called "laudable pus." This pus was regarded as being a good sign for recovery. Amputation of limbs resulted in death in about half of the cases operated upon, due to infection. Operations which involved opening of the body cavity usually were fatal. Lister was impressed by these facts and sought an explanation.

Lister was acquainted with the work of Pasteur and knew that there were such things as the minute bacteria. He observed that some wounds healed without the formation of pus. It occurred to him that minute organisms, such as those studied by Pasteur, might be in the wounds that developed pus. He thought that these organisms might be killed by the application of chemicals.

Antiseptics. Lister used carbolic acid on a compound fracture; that is, a fracture in which the bone had broken through the fleshy tissues to the outer surface. The injured tissues healed without the then common occurrence of infection. Thus Lister developed the principle of antisepsis: the destruction of microbes through the use of chemical substances. We now refer to an antiseptic[1] as a substance used to destroy microbes, or prevent their reproduction. Such antiseptics have become common in our everyday experiences.

Aseptic methods. Lister was in error with regard to one point. He first thought that the infection reached the wound principally through the agency of the air. As a matter of fact, the surgeons' hands and instruments were the chief sources of infection. Aseptic surgery developed from antiseptic surgery as the surgeons learned to wash their hands and instruments in antiseptic solutions *before* they performed operations. The aseptic method attempts to prevent microbes from entering the wounds. The antiseptic methods attempt to dispose of the microbes after they have entered the wounds. The aseptic method in surgery has made successful internal operations possible. Lister has been called "the greatest surgeon the world has ever known."

MANY DISEASES ARE KNOWN OR SUSPECTED TO BE OF GERM ORIGIN

In the preceding paragraphs we have learned that anthrax, a disease of cattle and sheep, is well established as a germ disease. The same might be said of chicken cholera.

Diphtheria. In the case of diphtheria the evidence for germ origin of the disease is quite convincing. Diphtheria is primarily a disease of children. The throat becomes inflamed and sore, and a characteristic membrane forms which makes swallowing difficult. Many characteristic bacilli (a type of bacteria) are found on this membrane. These are called the Klebs-Löffler bacilli, after the scientists who discovered them.

The Klebs-Löffler bacillus has been grown successfully in cultures. If a susceptible person is infected with material from such a culture, diphtheria will develop. If guinea pigs are infected with the culture, they develop symptoms of diphtheria. These facts serve to associate the Klebs-Löffler bacillus with the disease in question.

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[1] The word germicide is often used in referring to chemical substances which may be used to kill germs. Iodine, carbolic acid, bichloride of mercury, and sodium hypochlorite are common examples. When properly diluted they may be used externally as antiseptics. As most germicides are poisonous, care must be taken that none of these substances are swallowed.

Diphtheria toxin. The evidence does not end with these facts. It has been discovered that a culture of diphtheria bacilli contains a poison or toxin. A toxin is a poisonous product of the metabolism of bacteria. If diphtheria toxin alone is injected into the bodies of susceptible guinea pigs, the latter will develop many of the symptoms of diphtheria. The toxin is very powerful, and a single teaspoonful may be enough to kill some five thousand guinea pigs.

Then it was found that animals (guinea pigs), might be made immune to the effects of diphtheria toxin by giving them gradually increasing doses of diphtheria toxin. Starting with a very small dose that would not produce death, the dose was gradually increased from day to day until the animals were receiving very large doses indeed. What had happened? And why were these animals able to survive the large doses of toxin. The answer appears to be that when the toxin first entered their blood plasma, a second substance called an antitoxin was formed in the plasma. The antitoxin tended to neutralize the effect of the toxin. Later injections of toxin resulted in the development of more and more antitoxin in the blood plasma. Finally the animals were no longer susceptible to the effects of diphtheria toxin. In other words, they became immune to the disease.

Furthermore, it was found that if the blood serum of the toxin-immune animals was injected into nonimmune animals, which had just received a fatal dose of toxin, the latter would not die. They were protected by the antitoxin obtained from the blood serum of the toxin-immune animals.

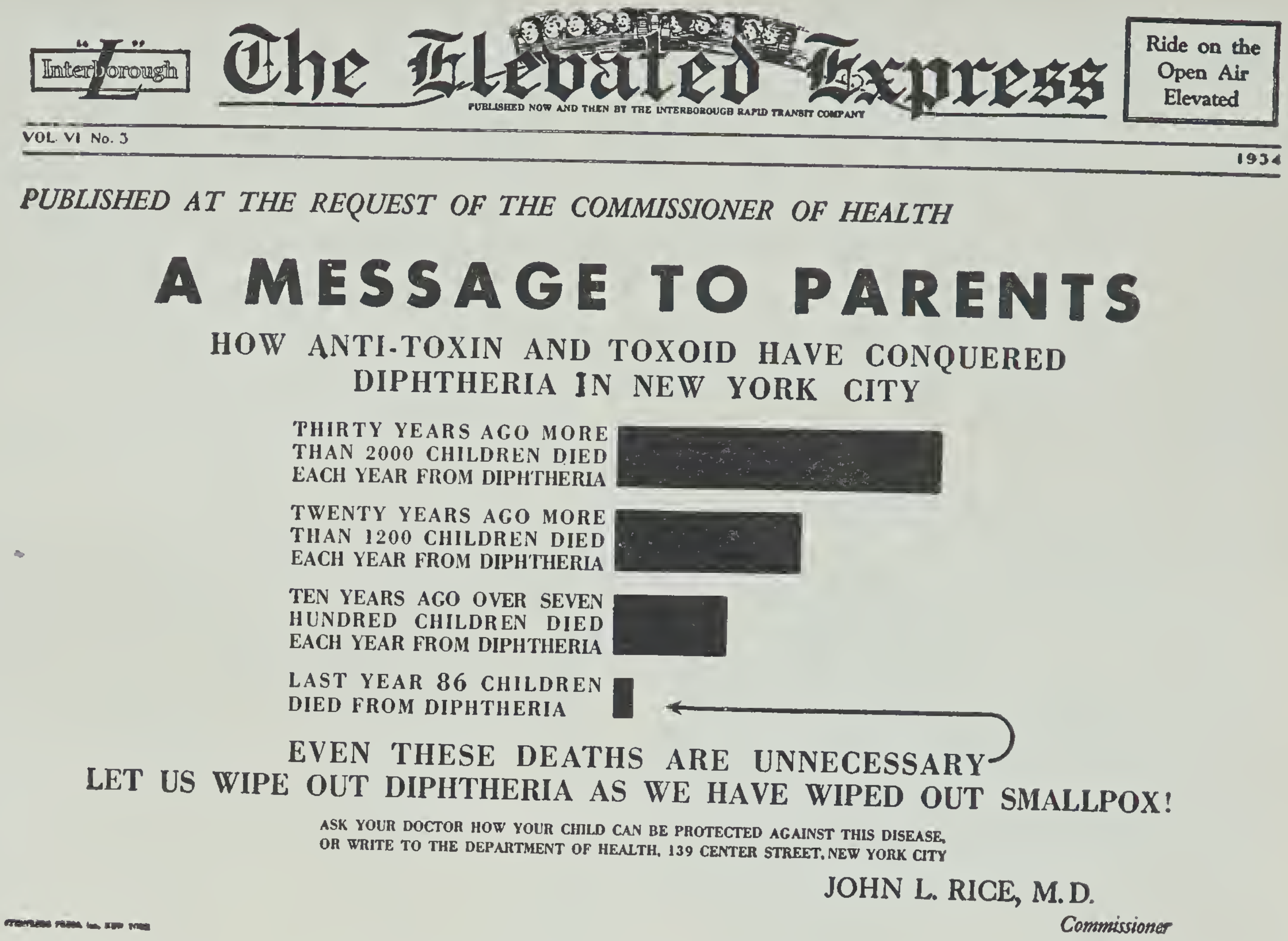
Diphtheria antitoxin. At the present time diphtheria antitoxin is obtained from the blood plasma of horses that have been given doses of diphtheria toxin. This antitoxin has proved quite effective as a remedy for diphtheria, if it is injected soon after the disease is developed. The toxin-antitoxin treatment is used to build up a more permanent immunity, in the case of individuals who have not had the disease. The Schick test is of value in determining whether or not a child is likely to contract diphtheria. In this test a tiny amount of diphtheria toxin is injected under the skin of the arm. If the area around the point of injection becomes inflamed it indicates that the child is susceptible to diphtheria (likely to get the disease if there is a source of infection). In the case of a child who has had diphtheria it is probable that no inflammation will occur. A new diphtheria "toxoid" has proved effective in rendering children immune to the disease. In the toxoid, the toxin has been weakened by the addition of a chemical substance.

Tetanus or lockjaw. Modern science has rather convincing evidence that tetanus is a germ disease. Tetanus also is known as "lockjaw," because one of the symptoms may be spasmodic contraction of certain facial muscles. It is a dangerous disease that has long been associated with deep wounds of any kind; wounds produced by stepping on nails, for instance. It appears that the tetanus organism lives to best advantage in places where there is little oxygen. Lockjaw is most likely to develop in cases of deep wounds.

The evidence linking the tetanus bacillus with lockjaw or tetanus is very convincing. This bacillus can be grown in pure cultures, and when mice are infected with material from such cultures they develop tetanus. The toxin from a tetanus culture will also produce symptoms of tetanus when it is injected into mice.

Tetanus antitoxin. An antitoxin for tetanus has been developed by giving horses increasing doses of tetanus toxin. This antitoxin appears to be a substance formed in the blood plasma, and the course of events seems to be similar to that involved in the development of diphtheria antitoxin. This antitoxin from the horse is injected into the human blood in cases where there appears to be danger of tetanus infection following an injury. The results have been satisfactory, although not so satisfactory as the results obtained from the use of diphtheria antitoxin.

Typhoid. In the case of typhoid fever, the typhoid bacillus has been isolated and raised in cultures in the laboratory. In a few cases people have accidentally become infected from such cultures, and have developed typhoid fever. This would rather definitely associate the germs in question with the disease. If it were possible to test the matter by infecting rabbits or guinea



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A MESSAGE TO PARENTS

HOW ANTI-TOXIN AND TOXOID HAVE CONQUERED DIPHTHERIA IN NEW YORK CITY

THIRTY YEARS AGO MORE THAN 2000 CHILDREN DIED EACH YEAR FROM DIPHTHERIA

TWENTY YEARS AGO MORE THAN 1200 CHILDREN DIED EACH YEAR FROM DIPHTHERIA

TEN YEARS AGO OVER SEVEN HUNDRED CHILDREN DIED EACH YEAR FROM DIPHTHERIA

LAST YEAR 86 CHILDREN DIED FROM DIPHTHERIA

EVEN THESE DEATHS ARE UNNECESSARY

LET US WIPE OUT DIPHTHERIA AS WE HAVE WIPED OUT SMALLPOX!

ASK YOUR DOCTOR HOW YOUR CHILD CAN BE PROTECTED AGAINST THIS DISEASE,
OR WRITE TO THE DEPARTMENT OF HEALTH, 139 CENTER STREET, NEW YORK CITY

JOHN L. RICE, M.D.
Commissioner

FIGURE 208. A poster used to advertise the importance of inoculation in the prevention of diphtheria. (Courtesy of the New York City Department of Health.)

pigs, this would have been done long ago. But unfortunately, the lower animals do not seem to suffer ill results when typhoid germs are in their bodies, therefore the ordinary methods of laboratory testing apparently are useless.

Typhoid inoculation. However, there is another line of indirect but significant evidence linking the typhoid bacillus with the disease typhoid fever. Typhoid fever has been widespread in many of the armies that have taken part in past wars. During three and a half months of the Spanish-American War, there were 20,738 cases of typhoid among a total of 108,000 men. This would be about one man in every five. But in the Great War the soldiers were given a typhoid inoculation consisting of killed typhoid cultures, with the result that there were only 1529 cases of typhoid among 4,128,478 men during the entire period of the war. This would represent about one man in every 27,000. It would appear that these inoculations were quite effective when we compare one out of five with one out of 27,000.

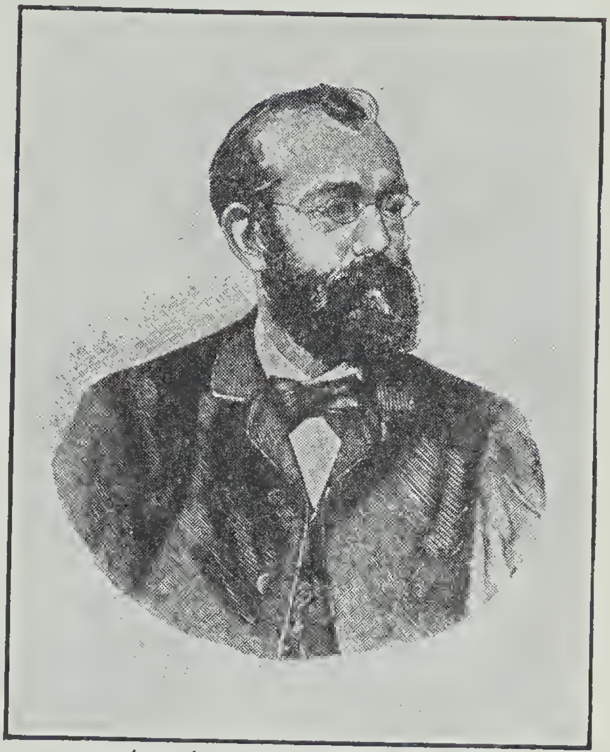
Leprosy. Records of leprosy date back to about 4000 B.C. It became disseminated all over Europe during the Middle Ages. It was soon recognized that the disease developed only after long and close association with people who had the disease. This resulted in the establishment of quarantines, and in the fourteenth century Europe had some 19,000 leper homes or "lazarettos," as they were called. The practice of establishing quarantines appears to have been effective, probably because the disease is not transmitted readily in most cases. At any rate, leprosy more or less died out in Europe during the fifteenth century. Some lepers are found in Europe today, however, and the disease is common in Africa, Australia, parts of Asia, some of the islands of the South Pacific, and parts of the United States. A bacterium that is associated with leprosy was isolated by Hansen in 1874. Recently, some advances have been made in the treatment of the disease and cures are effected in a number of cases.

Malaria. Malaria is definitely associated with a parasitic organism, although in this case the organism is a protozoan. Malaria will be discussed in Chapter XXXIII.

Tuberculosis. Tuberculosis is another very ancient disease.

It was not until 1882, however, that Dr. Robert Koch of Germany discovered the bacterial cause of tuberculosis. In Chapter XVII we learned something about the nature of human tuberculosis. We learned that children may be infected by the milk of tubercular cattle. Tuberculosis of the lungs is not usually developed as the result of such infection, but rather tuberculosis of other body tissues. This possibility may be avoided by using only Pasteurized milk, or milk from cattle that have been tested and proved to be free from tuberculosis. Pasteurization will kill a number of dangerous bacteria, including the bacteria of tuberculosis, diphtheria, and typhoid fever, but it must be done properly if this result is to be achieved.

As far as man is concerned, tuberculosis of the lungs is the most common form of the disease. In some cases this disease runs its course very rapidly and may result in death within from two weeks to three months. This type of tuberculosis, however, is not very common. A more common type is the "chronic" type in which the disease develops much more slowly.



American Museum of Natural History, New York.

FIGURE 209. Dr. Robert Koch, of Germany, who was born in 1843, and died in 1910. Koch employed scientific methods in his work. He held that the germ origin of a disease could only be established if four conditions were met. First, the organism must be found commonly in the body of a diseased animal. Second, the organism must be isolated in a pure culture. Then the same disease must be produced when this pure culture is given to a similar animal. Finally, large numbers of the suspected organism must be found in the body of the animal which has been given the disease. Koch announced his discovery of the tuberculosis germ in 1882, and the germ of Asiatic Cholera in 1883.

Probably all people, or at least the people living in cities, come in contact with the bacillus of tuberculosis sooner or later. In many cases the lungs become infected and scars are developed in them, but the individuals recover without knowing that they have had the infection. People who live in dark, poorly ventilated, and crowded places are likely to develop cases of tuberculosis. Hence we find that the improvement of living conditions has resulted in a decrease in the number of deaths from tuberculosis in some parts of the world. Some races of people are more prone to the disease than are others. The Negro and the Indians of North America are relatively susceptible. Among the European races the Scandinavians and the Irish appear to be most susceptible.

Is tuberculosis hereditary? Many people think that tuberculosis is an hereditary disease, but such is not the case. A child of tubercular parents usually is healthy at birth, but it is true that such a child is likely to become infected with tuberculosis early in life. If the parents have lived under conditions which favor the development of tuberculosis, the chances are that the child will live under the same conditions. The child has good opportunity to obtain the infection from its parents very early in life. Then, too, a lack of resistance which predisposes to tuberculosis appears to run in families. But generally speaking, children are not infected with tuberculosis at birth.

Asiatic cholera. Some attention previously has been given to Asiatic cholera, pneumonia, and bubonic plague. These diseases are associated with parasitic organisms. Asiatic cholera, as the name would indicate, is most common in Asia. But it has spread into Europe, and has made at least four appearances in North America, the first being in the year 1832. The organism associated with cholera is a bacterium.

Control of bubonic plague. We have seen that the rat flea acts as a carrier of bubonic plague. Since the flea in question bites both man and the rat, it serves to carry the disease from one to the other. The organism associated with bubonic plague is another bacterium. It was not until the rat and the flea were associated with the plague that any really effective control measures could be established. Control of the plague becomes a matter of the destruction of rats. Two methods have been developed by means of which people may be rendered immune to the plague, but the protection is only temporary in either case.

Up to this point in our discussion we have considered for the most part diseases which are rather definitely linked with certain germs. Among other important diseases which are not as yet *definitely* linked with specific germs are yellow fever, smallpox, infantile paralysis, measles, and influenza.

Smallpox. Smallpox presents an interesting case because a method of vaccination was introduced at an early date, long before Pasteur had performed his experiments and given his results to the world. The honor of the discovery goes to Dr. Edward Jenner of England, who developed a vaccination for smallpox in 1798. He had discovered that a disease of cattle known as cowpox was often transmitted to man in a mild form, and that the people who had had cowpox appeared to be immune to smallpox. He tried out vaccination with cowpox on an experimental basis and found it to be effective. The modern vaccination for smallpox is a development of this principle.

Smallpox is a very old disease which existed in ancient China and became common in Europe in the Middle Ages. Before an effective vaccination was developed, this disease literally killed people by the millions when it appeared in epidemic form. It is still a common disease in the United States, for although we have compulsory vaccination laws in most states, they are not always strictly enforced.

Filtrable viruses. It has only been a few years since study of certain plant diseases put us on the trail of the filtrable viruses. These viruses pass unchanged through stone filters that would retain any ordinary microbes. Under very great magnification some of them appear to contain some tiny dark spots. Such spots might be cells so small that bacteria would seem enormous by comparison. A more favored theory holds that filtrable viruses are free-living proteins, which can reproduce themselves. Some diseases now blamed upon viruses are mosaic disease of tobacco, the common colds, and true influenzas. It also has been suggested that infantile paralysis and yellow fever may be due to the presence in the human body of similar viruses.

THE HUMAN BODY HAS NATURAL DEFENSES AGAINST GERMS

In attempting to protect his body against the invasion of germs, man is trying to avoid being eaten. For many of these germs will destroy his body just as surely as it might be destroyed by a lion or a tiger. In fact, the lion and the tiger are less to be feared, for at least they are large enough to be seen and avoided.

Chemical defenses. Every human body is attacked by various of these germs during the course of a lifetime. Fortunately, a great many of these invasions are repulsed. This is made possible by the fact that the human body has certain definite chemical defenses which protect it in many cases.

For instance, gastric juice contains a small amount of hydrochloric acid which acts as a germicide, and kills a good many bacteria which enter the digestive canal. The bile, which is discharged into the small intestine, may kill some other bacteria. The intestine contains bacteria which live there all the time, and apparently have little or no adverse effect upon the human host. The wastes of these bacteria may serve to kill some dangerous bacteria which enter the intestine by way of the digestive canal.

The human skin tends to be more or less waterproofed by an oily secretion of the skin glands. No doubt this prevents the entrance of many bacteria. Various glands in the nose and throat secrete mucus, which entangles and retains invading bacteria and other microbes.

White corpuscles. One of the most interesting defenses against invading germs is found in the human blood. The white corpuscles act as the "sanitary police" of the blood. They gather at any injured or infected spot in large numbers, and they are able to ingest and destroy bacteria to a certain extent. But the defenses of the blood are not limited to the white corpuscles. It has been shown that blood plasma itself contains substances which have the power to destroy certain bacteria. For instance, blood from a cholera-immune person actually will dissolve cholera organisms.

Antibodies. Many efforts have been made to isolate from blood plasma the substance or substances which are responsible for what we call "immunity."[1] These substances are often referred to as "antibodies." No one has as yet succeeded in isolating pure antibodies from blood plasma. We do know that when certain substances, such as bacteria, enter the blood, immunity reactions occur. That is, specific antibodies which neutralize the effects of the invading bacteria apparently are developed. We should remember that a toxin is a poison secreted by some bacteria. An antitoxin is a substance which neutralizes the effects of a toxin.

VACCINATION AND INOCULATION ARE USED TO STRENGTHEN THESE DEFENSES

Inoculation. Long before Jenner developed vaccination as a defense against smallpox, a so-called inoculation for smallpox had been practiced by the Chinese. In fact this inoculation for smallpox was popularized in Europe after 1721. General Washington had all of his troops inoculated during the Revolutionary War. The method of inoculation consisted in transferring matter from a smallpox sore of one person to a small cut in the skin of another person. The second person usually developed a mild case of smallpox, and thereafter possessed a certain degree of immunity to the disease. This treatment was undesirable, however, because the persons inoculated became carriers of true smallpox for a time at least, and might infect other people. In the case of Jenner's vaccination with cowpox material, this danger does not exist.

Vaccination. It may be interesting to note how the vaccine used in smallpox vaccination is obtained. Smallpox material from a human victim is introduced into the skin of a calf. Strangely enough the calf does not develop smallpox but develops cowpox. The cowpox material is then used in vaccinating humans. It constitutes the so-called "vaccine" of smallpox. If the vaccination "takes," a local inflammation is developed. But in no case does the use of this vaccine produce a case of smallpox. Smallpox vaccination is a good protection against the disease.

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[1] Immunity is often referred to as being of two kinds. Active immunity is that resulting from the development of antitoxins because toxins are present. Passive immunity is that conferred (temporarily) by injection of antitoxins taken from some other organism.

As previously noted, some states have compulsory smallpox vaccination and others do not. Massachusetts requires this vaccination, while Minnesota did not have any such requirement between the years 1913 and 1923. Although Massachusetts had a far greater population than did Minnesota, there were, during these years, over a hundred times as many cases of smallpox in Minnesota as there were in Massachusetts.

It will be recalled that immunity to typhoid is secured by means of an inoculation[1] with a vaccine. Killed typhoid bacilli are introduced beneath the skin by means of a hypodermic needle. We have already noted the effectiveness of this method as evidenced by comparative data on American soldiers in the Great War and the Spanish-American War. In these, as in other cases previously discussed, vaccinations and inoculations serve to strengthen the natural defenses of the body against germs.

PUBLIC HEALTH

Public sanitation. Since the understanding of the relationship of bacteria to disease has become general, health authorities and private citizens are co-operating to improve public health. The problems of villages and cities are to destroy garbage, to dispose of sewage without pollution of streams, to secure a safe water supply, to supervise milk and food supplies, and to provide for quarantines. Sanitary measures have proved so effective that many American cities are freer from infectious diseases than are the surrounding rural regions.

Typhoid bacilli commonly enter the human body through the medium of contaminated water. Any water taken from ponds and streams *may* contain these organisms. The treatment of city water with chlorine kills typhoid bacilli. Typhoid has become far less common where this is done.

Personal hygiene. The role of the individual citizen is to preserve his own health, and to co-operate with others in maintaining the public health. Personal hygiene demands that no disease-producing bacteria colonize in the body. Since entrance to the body is usually by way of the nose, the mouth, abrasions, cuts, or through the medium of insects, these avenues should be guarded as much as possible against bacterial invasion. Prompt measures should be taken to check the development of infections and to prevent their communication to other people.

---

[1] Sometimes called a vaccination.

Sanitation in the country. Bacteria breed wherever moisture, moderate temperature, and food materials are found. Home surroundings must be kept clean and free from rubbish. Cesspools, out-of-door toilets, manure piles, garbage heaps, and dirty stables are avoidable nuisances — even on farms. Septic tanks should replace cesspools. Manure should be spread on the fields at frequent intervals. Animal quarters should be cleaned periodically, and the walls washed with lime. Chloride of lime or ordinary lime should be used freely in all places where decaying organic matter is obliged to accumulate for short periods. Otherwise, piles of decaying materials may become breeding places of flies which carry germs. Private water supplies must be guarded from pollution. Care must be taken that wells or springs receive no drainage from cesspools or manure piles.

Summary. In conclusion, we can now begin to realize the tremendous advances that have been made in man's struggle to suppress his parasitic enemies. Superstitions in many cases have given away to scientific facts. In the course of three centuries, the *average* human life has been nearly tripled, largely because the rate of infant mortality has been lowered. Knowledge of the germ theory of disease has made possible at least the partial suppression of bubonic plague, malaria, tetanus, diphtheria, typhoid fever, and other diseases. Aseptic and antiseptic methods have been developed in surgical work. Public health measures have made many cities freer from disease than surrounding rural areas.

We now have available an effective antitoxin and a toxoid for diphtheria, an antitoxin for tetanus, vaccination as a prevention of smallpox, preventive inoculation for typhoid fever, and some other preventives not discussed here. Much remains to be learned, especially in connection with such problems as those raised by filtrable viruses, and such diseases as infantile paralysis, influenza, and common colds. Many scientists are now at work upon these problems, and it is not too much to hope that some of them will be solved in the near future.

SUGGESTED ACTIVITIES

Scientific methods

A scientist makes his knowledge available for use in improving the conditions of human life.

1. Read how to make culture plates of agar (see textbook on bacteriology). With the aid of the instructor, prepare several culture plates for use in the following demonstrations.
2. If possible, obtain a living house fly. Allow the fly to walk across an agar surface. Cover the culture plate and keep it at room temperature for four days. Examine the culture plate for the presence of bacteria.
3. As in 2 above, prepare cultures of material (*a*) scraped from beneath the fingernails, and (*b*) from around the teeth. (*c*) Compare a culture obtained by touching the agar surface with an unwashed hand, with a culture produced by touching a culture plate with the fingers of a newly washed hand.
4. On three culture plates place material scraped from beneath the fingernails. Treat the plates as follows:
   - *a*. Plate A: no treatment (control).
   - *b*. Plate B: immerse in 70 per cent alcohol for ten minutes.
   - *c*. Plate C: immerse in 10 per cent formalin for ten minutes.

   Cover the three plates and allow them to stand at room temperature for four days. Examine them for the presence of bacteria, and explain the results.
5. Read *Microbe Hunters* by De Kruif. Report on the lives and works of (*a*) Leeuwenhoek, (*b*) Koch, and (*c*) Pasteur.
6. Prepare a chart of common communicable diseases including smallpox, diphtheria, tuberculosis, typhoid fever, and any others concerning which you are able to obtain data. In four columns list (*a*) how the germs gain access to the human body, (*b*) means of transmission, (*c*) methods of obtaining immunity (if any), and (*d*) methods of hygiene and control.

SUMMARY OF PRINCIPLES

1. Many dangerous diseases are caused by parasitic, microscopic organisms.

2. Some germ diseases which have been common for centuries are the result of the transmission of microbes from person to person.
3. The modern "germ theory" is the result of work done by Louis Pasteur and his followers.
4. Sir Joseph Lister developed antiseptic methods in surgery.
5. The human body has various natural defenses against germs.
6. Vaccination and inoculation are methods used to strengthen natural defenses against the germs of disease.
7. Public health measures include garbage and sewage disposal, a safe water supply, quarantining, and supervision of milk and food supplies.

GUIDE QUESTIONS

1. State the "germ concept" of disease. Who is responsible for man's first understanding of the principles involved in this concept?
2. Distinguish "epidemic" from "endemic" diseases.
3. What are "plagues"? Mention some ancient superstitions about them.
4. Discuss briefly the meaning and importance of preventive medicine.
5. Describe one experiment of Pasteur.
6. What is rabies? How is it now controlled?
7. Discuss what is meant by "antiseptic" and "aseptic" methods.
8. Distinguish between "toxin" and "antitoxin."
9. Describe the Schick test and discuss its significance.
10. What evidence can you give that typhoid inoculation is desirable?
11. What are environmental conditions favorable to the development of tuberculosis?
12. Discuss natural defenses of the human body against invasion of germs.

BOOKS TO READ

Bayne-Jones, S. *Man and Microbes.*
Broadhurst, Jean. *Home and Community Hygiene.*
De Kruif, Paul. *Microbe Hunters.*
Downing, E. R. *Science in the Service of Health.*
Fitzpatrick, F. L. *The Control of Organisms.*
Haggard, H. W. *The Science of Health and Disease.*
Palmer, E. L. *Poisons, Diseases, and Medicines.* Cornell Rural School Leaflet, vol. 26, no. 2.

CHAPTER XXXII

INVERTEBRATES IN RELATION TO MAN

Problem:

What invertebrates are of importance to man?

MANY ANIMALS AFFECT THE WELFARE OF MAN

Foreword. When we studied a group of plants and animals living in a fresh-water pond, we found that the welfare of any one kind was directly or indirectly affected by the presence of all of the other species. A similar situation exists in the case of man. All plants and animals living in the regions which he inhabits affect his welfare. In some cases the importance of certain species is slight; in other cases certain plants and animals have direct and important effects upon man's welfare. From the human standpoint, a given species may be desirable, undesirable, or of no great consequence.

Competitors and natural enemies. Undesirable organisms may affect man as competitors, as natural enemies, and in less direct ways. Competitors are organisms which use the materials — including food materials — that man might otherwise devote to his own interests. Natural enemies include organisms which may destroy man directly. The large animals which were the natural enemies of primitive man have been greatly reduced in numbers. The small, parasitic organisms, however, remain as active natural enemies of the human race.

On the other hand, many organisms are useful to man in a variety of ways. We call these useful organisms "beneficial" species. The competitors and natural enemies of man are called "injurious" species. Species having slight or insignificant relationship to man's welfare are termed "neutral." It is our purpose in this chapter to study some of the invertebrates (animals without backbones) which affect man's welfare. Obviously, because of the limitations of space, only the more important species will be discussed.

PROTOZOA

There are many different kinds of protozoa in the world. Most of them probably do not greatly affect our welfare. Some types, however, are injurious because they are responsible for human diseases, or diseases of domesticated animals.

Dysentery. Dysentery is one of the common illnesses of tropical countries. One type — amoebic dysentery — is due to the presence of Endamoeba histolytica in the human intestine. Apparently Endamoeba is a common parasite of man in most regions of the world, but is not likely to cause trouble except in warm countries. At least two dozen other protozoa are known to live in the human intestine.

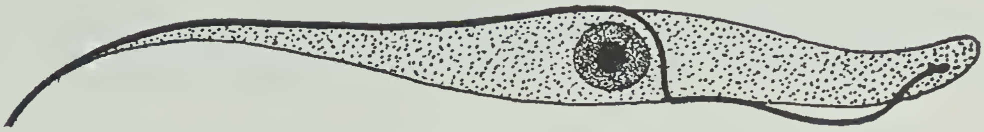

FIGURE 210. Diagram of a trypanosome.

Sleeping sickness. African sleeping sickness is a common and often fatal disease of that continent. It is caused by two species of protozoans, which live in the blood stream. They are of a type known as trypanosomes (see Figure 210). These parasites are conveyed to man by bloodsucking tsetse flies. Other kinds of trypanosomes are known or thought to cause diseases of man and of livestock.

Malaria. Plasmodium, the organism of malaria, is another important protozoan. Three species of this genus produce different types of malaria. Before the underlying causes of malaria were known, this disease was a natural barrier to the migration of white races into tropical regions. A more complete treatment of this disease will be found in the following chapter.

SPONGES

Sponges. Some of the sponges are of the colonial type: a number of individuals living together. These colonial types are found mainly in tropical and semitropical seas, such as the Mediterranean Sea. They are also found along the coasts of Central America, Florida, and the West Indian Islands.

Sponges are attached to the bottom in adult life. They develop extensive skeletons, which in some of the sea species are of the flexible material known as spongin. It is this spongin skeleton that forms the sponge of commerce. The sponges are brought to the surface by divers or through the use of iron hooks on long poles. Then the sponges are spread out on floors or decks and the living cellular material is allowed to die and decompose. When decay is well under way, the sponges are washed until only the skeletons remain.

CŒLENTERATES

Most of the members of the Phylum Cœlenterata have but little economic importance. The corals, however, are an exception.

Corals. As in the case of the sponges, there are two general types of corals, the solitary and the colonial. In the case of solitary types, individuals lead separate and independent lives. In the case of colonial corals, a number of individuals live attached to one another. Like sponges, corals are attached (sessile) in adult life. They develop extensive skeletons, which are composed mainly of calcium carbonate. Some of the skeletons of the rarer and more delicate modern corals are used as ornaments. Most of these "precious corals" come from the Mediterranean region and from Australia. Two species of corals are used as human food in Italy.

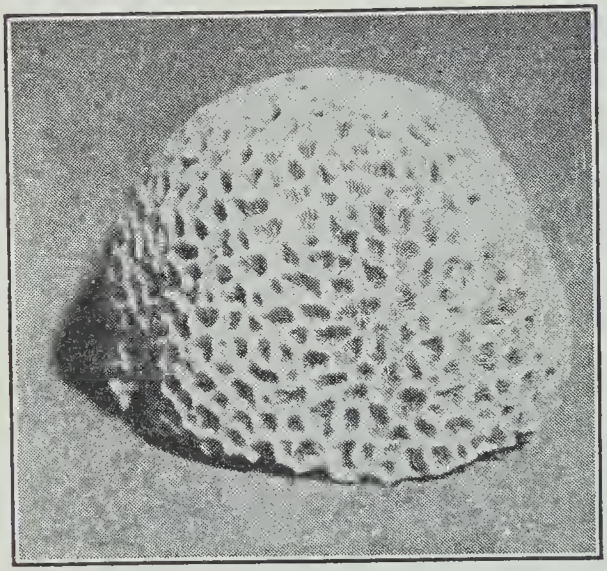
FIGURE 211. The skeleton of a colonial coral.

Coral reefs. Coral colonies form reefs in our modern seas, and reefs frequently are a menace to ships. The Great Barrier Reef of

Australia is perhaps the largest modern coral reef, having a length of over eleven hundred miles and a maximum width of thirty miles. A coral colony will begin its development at the bottom in rather shallow water, and finally will build up to the surface, and even above the surface. Some coral formations that build up above the surface of the sea become coral islands.

FLATWORMS

Flukes. A considerable number of flatworms are parasitic; some of them are parasitic upon man or upon organisms that furnish food for man. These species are considered to be injurious. The flukes belong to this group. Some species of flukes live in the bodies of pigs, sheep, and cattle. Other species are human parasites, and their presence in the human body may result in the death of the host. Most of the species which are parasitic upon man are found in Africa and in the Orient.

The tapeworms also are important parasites of man and domesticated animals. Among the more important types are the beef tapeworm (Tænia saginata), and the pork tapeworm (Tænia solium).

Beef tapeworm. Tænia saginata is the common human tapeworm. It requires two hosts in the course of its life cycle: man and the cow. The adult worm lives in the human intestine. Its body consists of a head and a number of segments. The body may attain a length of thirty feet, depending upon the number of segments developed. The head bears four suckerlike structures that serve to attach it to the wall of the intestine.

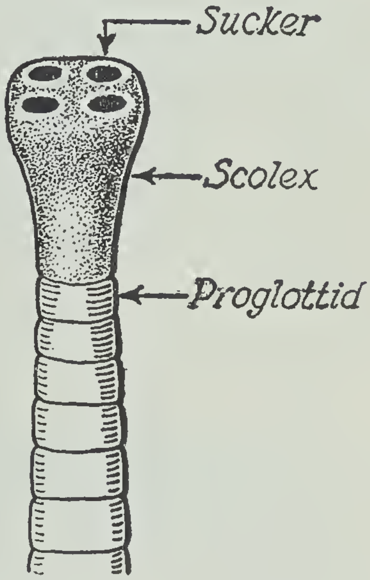

FIGURE 212. Diagram showing the head and adjoining segments of a tapeworm.

The tapeworm lies in the human intestine and absorbs digested food through its body wall. This, of course, draws upon the host's supply of nourishment. As the segments mature, they become filled with fertilized eggs. Such mature segments pass to the exterior with the wastes, but meanwhile the eggs have developed into embryos. The embryos may come to lie on grass, or be in the water of ponds and streams. If these embryos are swallowed by cattle, they will bore through the walls of the intestines and pass out into the muscles, where they become encysted (enclosed in protective cysts). The encysted parasites are known as cysticerci. Now if the beef of the infested cattle is eaten by man without having been sufficiently cooked to kill the parasites, the latter will be liberated from their cysts and assume the adult form in the human intestine. These adults may be driven out of the intestine by taking certain purgatives, as prescribed by a physician.

Pork tapeworm. Tænia solium is a more dangerous species from the human standpoint. Ordinarily, the adults live in the human intestine, and the cysts are formed in the muscles of pigs. Human infestation results from eating incompletely cooked pork that contains the cysticerci. Occasionally, embryos produced by the adult worms in the human intestine do not pass to the exterior with the wastes, but remain in the body and encyst themselves in the human muscles. It is quite possible to expel adult tapeworms from the intestine by using purgatives, as in the preceding case. Cysticerci in the muscles, however, cannot be destroyed by using drugs. The cysticerci may develop in vital spots where their presence will sooner or later produce serious results. This danger may be avoided, however, by cooking pork thoroughly before it is eaten.

ROUNDWORMS

The roundworm group also contains a large number of parasites that affect the well-being of man, domesticated animals, and cultivated plants. The great majority of these parasites are injurious.

Hookworm. One of the important species is the American hookworm (Necator americanus). It is a small species, less than half an inch in length, and its mouth is armed with puncturing structures. The adults live in the stomach and intestine of man, where they attach themselves to the walls and suck blood. Although the worms are small, they often are present in large numbers. The host suffers from loss of blood, and the presence of poisonous waste products secreted by the parasites. Victims are often thin, pale, listless, and lacking in mental alertness.

There are two sexes in the case of the hookworm. The females produce large numbers of eggs, which pass to the exterior with the wastes, and develop into boring larvæ. The larvæ usually enter the human body by penetrating the skin. Then they are carried by the blood to the lungs. Here the larvæ bore out into the air spaces. Then they pass up the bronchial tubes, the trachea, the larynx, and down the œsophagus to the stomach and intestine. Incidentally, the lungs may be injured by the boring activities.

Hookworm infestation is common in the tropics and the subtropics. It formerly was very common in the southern part of the United States, but is becoming less prevalent under the influences of health education and medical treatment. Children often become infested because they go about barefooted in hookworm areas. Sanitary disposal of wastes tends to prevent infestation. A successful medical treatment has been devised.

Trichina worm. The trichina worm (Trichinella spiralis) is another highly injurious species that appears periodically, and usually unexpectedly, over a wide range of localities. It is parasitic upon man, the pig, and the house rat. Both adults and cysticerci appear in the bodies of one host.

Trichina worms are small, the adult females being less than a millimeter in length, and the adult males about a millimeter and a half in length. The adults live in the intestine and each female

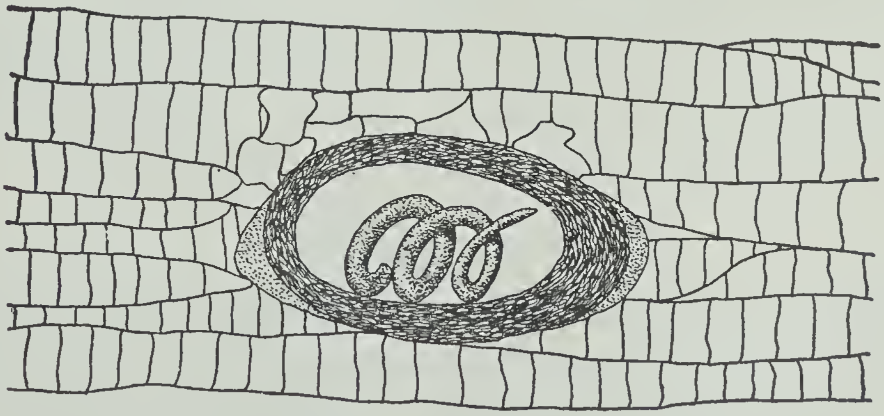

FIGURE 213. Diagram of a trichina worm encysted in muscle tissue.

may bear about ten thousand young. The young, or embryos, bore out into the muscles and form cysts. These cysts are so small that they cannot be seen by the unaided eye, but they may occur in very great numbers.

Man becomes infested by eating rare, infested pork. *Thorough* cooking of the pork will kill the parasites. If the parasites are not killed, they will be liberated when the cysts dissolve in the human stomach, and will then develop into adults. The adult females will now produce embryos which burrow out into the human muscles. Once the parasites have entered the muscles, they cannot be driven out of the body, although purgatives will expel the adults from the intestine. Death may result unless the victim receives medical treatment soon after the infested pork is eaten. This case furnishes us with another good reason why pork should be well cooked before it is eaten. Only a small percentage of pork contains these parasites. The cysts, however, are so small that they cannot be detected by examining the meat with the unaided eye.

Sugar-beet nematode. The sugar-beet nematode (Heterodera schachtii) is an example of a roundworm that parasitizes a cultivated plant. It is found in the beet fields of both Europe and North America, and its presence often becomes a real menace to the industry of raising sugar beets. It is another very small species. The larvæ bore into the beet roots and feed upon the sap as they grow. Many of the plants are killed or their growth is retarded.

A beneficial roundworm. Mermis albicans will be mentioned in connection with the roundworm group, because it is beneficial from the standpoint of man. It is parasitic upon grasshoppers, and grasshoppers are undesirable insects. The parasites develop in the bodies of the grasshoppers, often killing them.

ECHINODERMS

Starfishes, sea urchins, and sea cucumbers. Most of the members of the echinoderm group are neutral or of little consequence, but there are certain exceptions. Starfishes are often found in great numbers along seacoasts in shallow water. They are in-

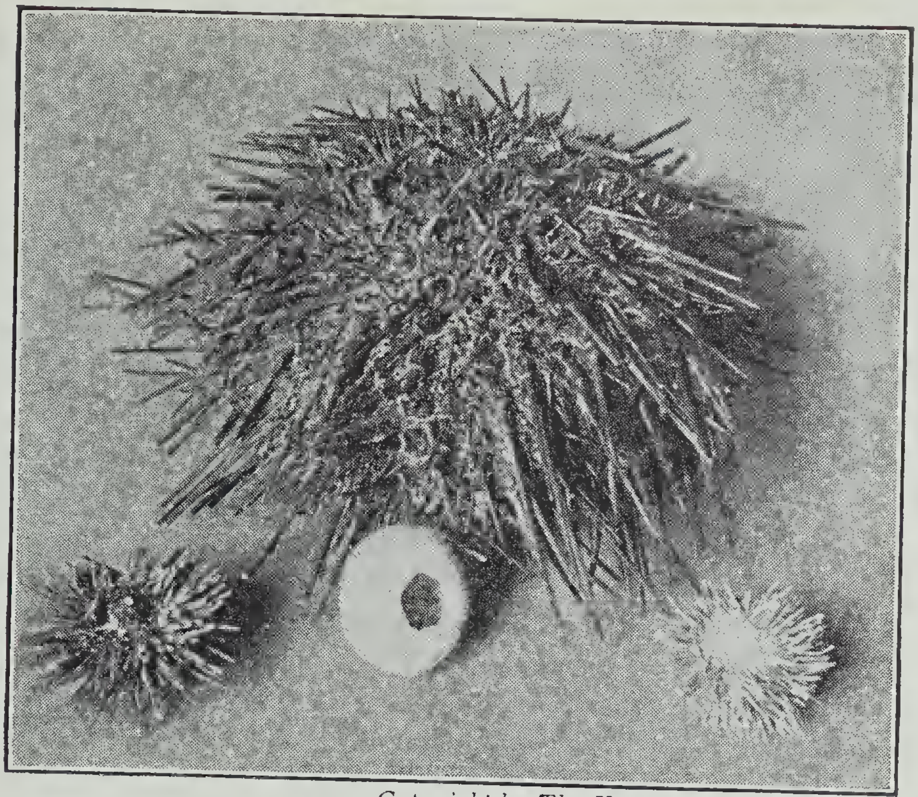

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FIGURE 214. Sea urchins. These marine animals belong to the echinoderm group. What other common marine animals belong to the same group?

jurious to the extent that they feed upon oysters and mussels. Sea urchins have some value as human food. During the reproductory season their bodies become filled with eggs and they are collected in the West Indies and the Orient to be sold as "sea eggs." Sea cucumbers also are used as human food in the Orient and the islands of the Pacific Ocean. They are found in the shallow waters along the coasts. Their leathery bodies are boiled, dried, and smoked to form the commercial product known as "trepang."

ANNELID WORMS

Earthworms. We have previously mentioned the burrowing habits of earthworms. These animals are often very numerous in a given area, especially if the soil contains a good deal of organic material. In bringing their castings (waste products) to the surface, they gradually build up a layer of fine dirt. This layer of dirt tends to cover decaying materials, stones, and other objects which lie upon the surface of the soil. The ground is rendered more porous by the burrows, therefore rain water can soak in more readily. All of these factors tend to facilitate the raising of cultivated crops.

Leeches. Leeches are parasitic annelids. The medicinal leech (Hirudo medicinalis) formerly was used extensively in the practice of medicine for the treatment of a variety of ailments. It was placed upon the human skin and allowed to suck out a quantity of blood. "Leeching" is no longer commonly practiced, except possibly in the removal of blood from bruises. Other species of leeches are injurious because of their attacks upon birds, fishes, domesticated animals, and even man. Some aquatic species of leeches are reported to be used as human food in certain parts of the world.

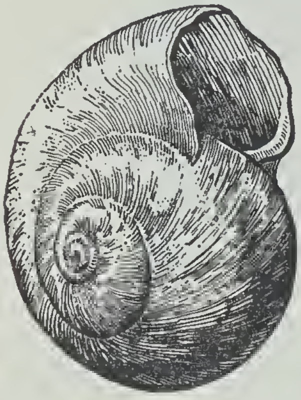


FIGURE 215. A snail shell. Snails are members of the mollusk group.

MOLLUSKS

Snails. Snails have been and still are used as human food, although the supply is limited. In fact, they are raised for the market on snail farms in France and Italy.

Bivalves. Many of the bivalves (two similar valves or shells) are highly useful to man. The oysters, scallops, and mussels are found along the seacoasts, and the fresh-water clams are found in inland streams.

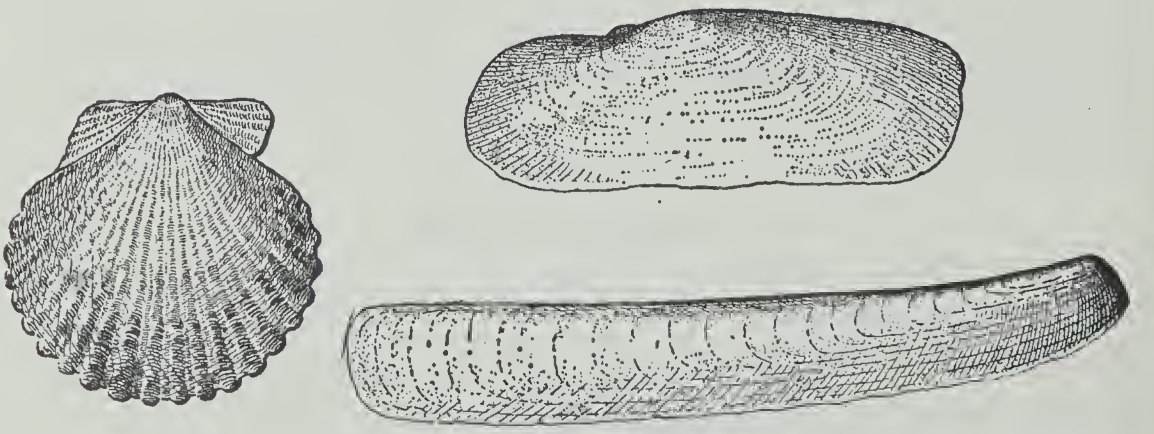
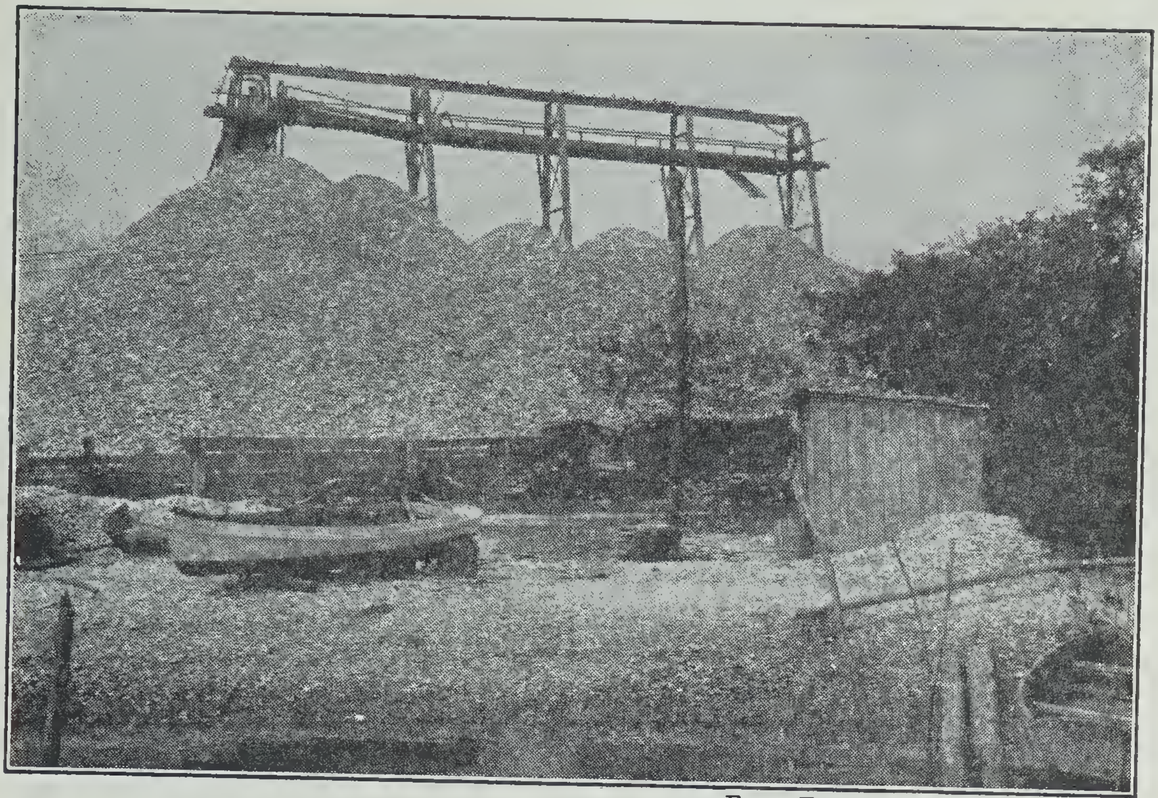


FIGURE 216. Three species of marine bivalves. Bivalves are members of the mollusk group.



From Ewing Gallcway, New York.

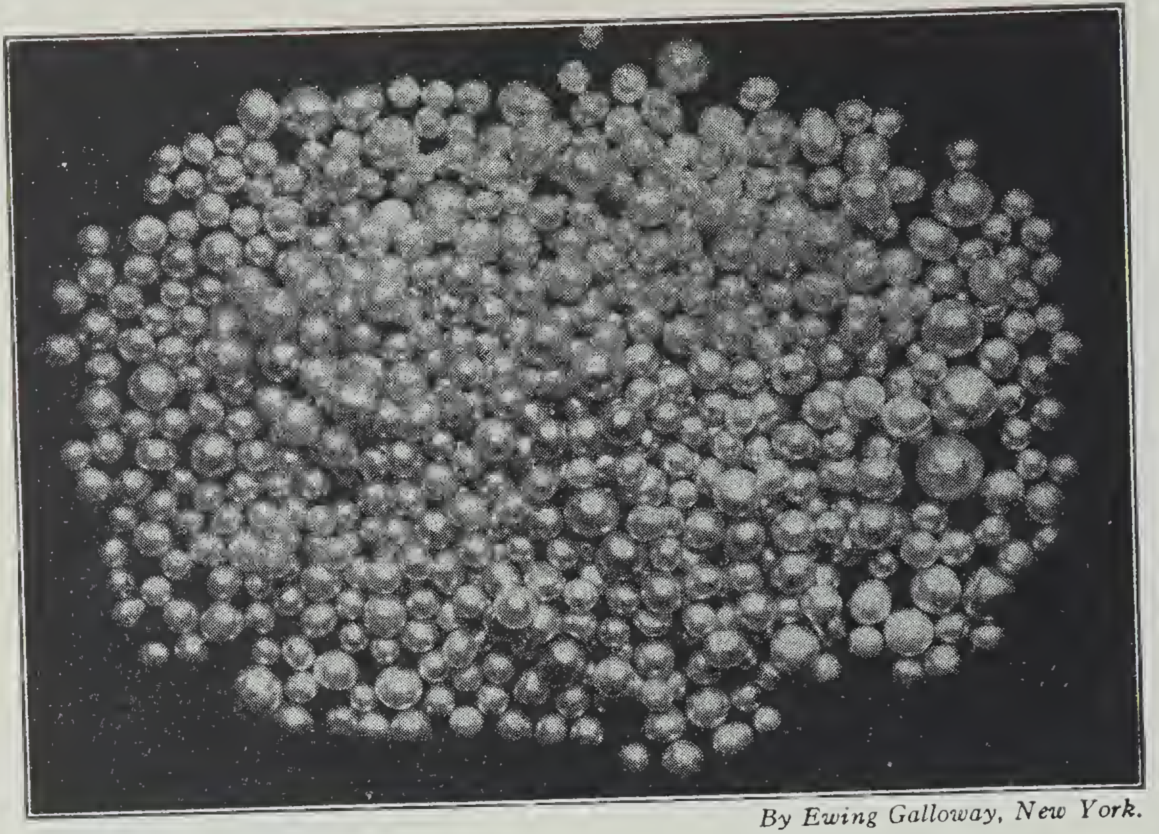
FIGURE 217. A pile of oyster shells. Such shells are used in road-building, and for other purposes.

Edible species of oysters are found along the Atlantic, Pacific, and Gulf Coasts of the United States, the coast of Japan, and the coast of Europe. The species of our Atlantic Coast is Ostrea virginiana.

Oysters. Ostrea virginiana lives attached to hard objects when in the adult state. It is found in shallow water, where enough microscopic food material is available. Since the animals are fixed in position, a bottom of shifting sand or mud is unfavorable to their existence.

In recent years the natural supply of oysters has been failing, and the raising of oysters, or "oyster culture," is now practiced in scattered localities along the Atlantic Coast.

Long-neck clam. The soft or long-neck clam (Mya arenaria) is almost as famous as the oyster, because it has long been used in the making of clam chowder. This species is found on the Atlantic Coast and differs in habits from the oysters and mussels in that it is found buried in the sand or mud along the shore.



By Ewing Galloway, New York.

FIGURE 218. A group of pearls taken in the Australian region.

Pearl products. The shells of fresh-water clams and marine bivalves are composed of calcium carbonate. The inner surfaces of such shells are covered with a harder and often lustrous material called mother-of-pearl, or nacre. This nacre is secreted by a fleshy layer known as the mantle, which surrounds the body proper. Apparently the smooth surface of the nacre is not irritating to the fleshy tissues it encloses.

Shells of many different bivalves are used to produce pearl buttons, various ornaments, and inlays. Many of the larger items come from the big, marine, pearl oyster, which is found in some parts of the Pacific and Indian Oceans. Fresh-water clams from our own rivers have been used largely to make pearl buttons. In recent years the natural supply of clams has become alarmingly low in some streams, and it has been necessary to cut down on their use to some extent.

Pearls. If a grain of some foreign substance becomes lodged within the shell of a clam or oyster, or if a parasite becomes encysted in the mantle layer, the clam will be irritated. Then the mantle layer is likely to secrete mother-of-pearl about the irritating substance. It is in this way that most true pearls are formed. The majority of them are not very usable, because they are irregular in shape, of poor color, or cemented to the shell. Now and then, however, a really good pearl is formed. We obtain such pearls from the marine pearl oyster, and from fresh-water clams of North America and Asia.

The Orientals long have known that it is possible to place a small object between the valves of a clam, and literally force the clam to secrete a layer of nacre about it. As a rule the object then becomes cemented to one of the valves. During the past decade, however, a Japanese concern has been producing "cultivated" pearls in quantity. A special operation method is used to insert a spherical object *in the fleshy tissues* of the bivalve. This method represents the work of Baron K. Mikimoto, and pearl oysters are used to produce the pearls. A different technique of insertion has been used experimentally in this country, and with success, although cost of production is high. Cultivated pearls are not to be confused with the many different artificial pearls made in laboratories.

CRUSTACEANS

Lobsters. The American lobster (Homarus americanus) is the most important member of this group. It is found along the Atlantic Coast of North America. The use of lobsters in large quantities has resulted in a sharp reduction of the natural supply. This, in turn, has resulted in higher prices. Efforts are being made to conserve the supply by protecting the young lobsters and by restocking the waters. Other species of lobsters are found along the coast of Europe and the Pacific Coast of North America.

Shrimps and crabs. Shrimps and crabs also are of commercial importance. Shrimps are found along the Gulf and Pacific Coasts of North America, some of the species in fresh water. Crabs are found in many parts of the world, and are especially common in tropical and subtropical seas. A few species are terrestrial. The natural supply of edible crabs has been reduced greatly in many localities.

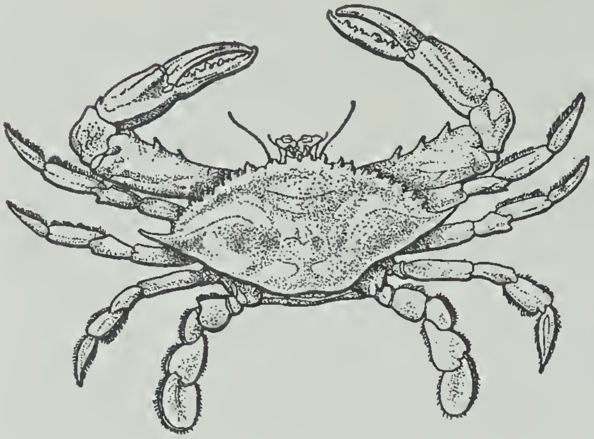


FIGURE 219. A crab. Crabs are members of the crustacean group.

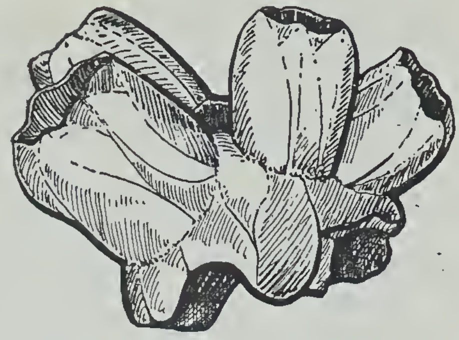


FIGURE 220. Skeletons of barnacles. Barnacles are crustaceans which live attached to solid objects in the water (sea).

Crayfish. Crayfish of various species also have been used as human food, especially in Europe. The crayfish of Eastern North America belongs to the genus Cambarus, while the larger crayfish of the Pacific Slope is Astacus. Crayfish can be raised for commercial purposes; in fact, this has been done in Europe.

Crayfish are injurious, however, in some parts of North America. Their burrows drain water from irrigation ditches in the arid parts of the country. In parts of the South they are considered to be pests because they eat and destroy young cotton plants.

ARACHNIDS

Venomous spiders. The venomous spiders are found largely in the tropics or subtropics. However, some of the North American spiders are capable of inflicting unpleasant, and in some cases dangerous, bites. The black widow spider (Latrodectus mactans) of our Southwest is at times dangerously poisonous to man.

Scorpions. Scorpions are likely to be found in warm, semiarid countries, such as the southwestern part of the United States. They have venomous stings, the danger to man depending upon the size of the scorpion, the location of the wound, and other factors.

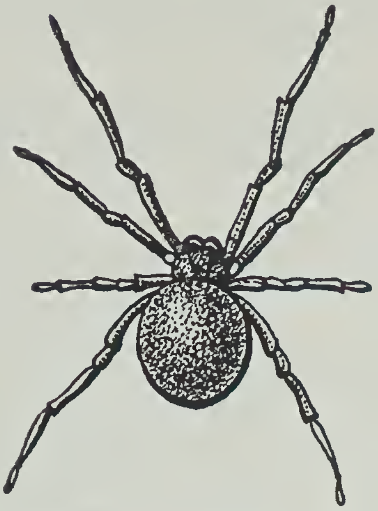


FIGURE 221. A venomous spider (Latrodectus).

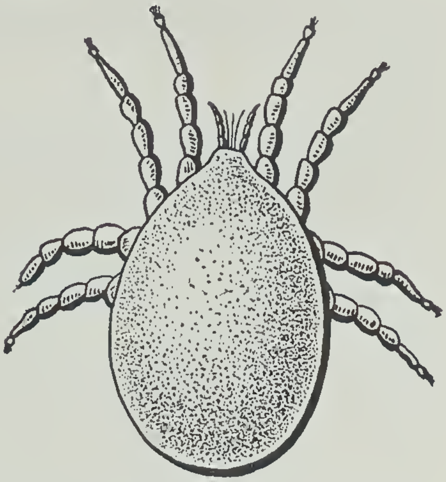


FIGURE 222. A tick. Ticks are members of the arachnid group. How many legs does an arachnid possess?

Chiggers. Chiggers are found in scattered localities of North America. They appear to require a fairly mild climate. Chiggers attach their mouth parts to the human skin, and their presence is likely to result in painful irritation.

Summary. We note that a number of invertebrates affect the welfare of man. Some are associated with human diseases, or are parasitic upon cultivated plants or domesticated animals. Others provide materials of commerce, such as sponges and pearl buttons. A number of invertebrates, such as oysters and lobsters, are used as human food. In this chapter no special discussion of insects has been included, although insects are invertebrates. Owing to the fact that insects have such great economic importance, the two following chapters are devoted to a study of these animals.

SUGGESTED ACTIVITIES

Scientific methods

A scientist practices necessary skills in order to bring about the desired conditions in his experiments.

1. If slides bearing Endamœba or trypanosomes are available, examine them with the aid of the microscope (demonstration).
2. If available, study museum specimens of sponges and corals.

3. After consulting the reading references at the end of this chapter, prepare a report upon the methods used in raising (*a*) sponges, or (*b*) oysters.
4. After consulting the reading references at the end of this chapter, prepare a report upon the growth of coral colonies, and the formation of coral reefs and coral islands.
5. With the aid of a microscope, examine the head and attached segments of a tapeworm (demonstration).
6. If slides bearing roundworms (such as a hookworm) are available, examine them with the aid of the microscope.
7. Using a microscope or microprojector, study a section (slide) showing trichina worms encysted in muscle tissue. Examine the slide with the unaided eye and satisfy yourself that the cysts are invisible unless they are seen with the aid of a lens.
8. Examine living or preserved specimens of snails, clams, oysters, squids, and other mollusks. Examine structures and products made from the shells of some species.
9. After consulting the reading references at the end of this chapter, prepare a report upon the life cycle and economic importance of the oyster.
10. Examine living or preserved specimens of crustaceans, such as lobsters, shrimps, crabs, and crayfish.

SUMMARY OF PRINCIPLES

1. Many animals affect the welfare of man, either directly or indirectly.
2. While most protozoa are probably neutral, some species are associated with human diseases.
3. Some sponges have commercial uses.
4. Coral growths may result in the formation of reefs and islands.
5. A number of flatworms, including species of tapeworms and flukes, are parasitic upon man and his domesticated animals.
6. The roundworm group includes such important parasites as the trichina worm and the American hookworm, which are parasitic upon man.
7. Some of the activities of earthworms are useful to man.
8. Leeches are parasitic upon man, birds, fishes, and other animals.
9. Oysters and some species of marine clams are used extensively as human food. The shells of clams and oysters are used in the manufacture of pearl buttons and similar articles of commerce. Most good marine pearls are obtained from the pearl oyster, although many come from fresh-water clams.

10. Lobsters, shrimps, crabs, and crayfish are important in relation to the human food supply.
11. Most venomous spiders are found in tropical regions.
12. Scorpions are armed with venomous, stinging structures.

GUIDE QUESTIONS

1. Give an example of an injurious species of animal. A beneficial species.
2. Discuss three diseases associated with the presence of protozoans in the human body.
3. Discuss the commercial utilization of sponges.
4. Discuss the formation of coral reefs and islands.
5. How do tapeworms and trichina worms gain entrance to the human body? How may this be avoided? What species are most likely to cause serious injury to the host?
6. Discuss the economic importance of starfishes, sea urchins, and sea cucumbers.
7. Discuss the importance of the earthworms.
8. Discuss five mollusks that are used as human food.
9. How may the shells of certain bivalves be utilized in commerce?
10. Discuss the formation of pearls.
11. Discuss three crustaceans that are used as human food.

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Beebe, W. *Beneath Tropic Seas.*
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Hegner, R. W. *Practical Zoology.*
Metcalf, Z. P. *Textbook of Economic Zoology.*
Reese, A. M. *Outlines of Economic Zoology.*
Tressler, D. K. *The Wealth of the Sea.*

CHAPTER XXXIII

INSECTS AND DISEASE

Problem:

What kinds of insects serve to carry or to transmit diseases?

INSECTS ARE AMONG THE MOST SUCCESSFUL ANIMALS

Insects as successful animals. In our previous studies we may have been surprised to learn that the majority of described species (including all organisms) are insects. About 640,000 species of insects have been named and described and it is entirely possible that from eight to ten times this number remain unclassified. This suggests that the insect group is one of the most successful animal groups. The success of the insects may be attributed to three general causes, which are as follows:

1. Many species are adaptive.
2. Many species reproduce rapidly.
3. Insects are relatively small in size, and survive by virtue of what might be called a "survival of the inconspicuous."

Distribution of insects. Insects are cold-blooded animals. Consequently, we find them to be most numerous in the tropics and subtropics where they can be active the year round, and where a continuous supply of food is available. However, many species are found in temperate zones.

Many of the insect species are of no known importance to man at the present time. On the other hand, many other species are of great importance. Injurious species of insects affect man in two general ways:

1. As carriers of disease.
2. As competitors for food supply.

In this chapter we shall discuss the first of these propositions. It is well to note that not all species of insects are injurious; many are neutral, and some are definitely beneficial.

SOME MOSQUITOES TRANSMIT MALARIA AND YELLOW FEVER

Mosquitoes. Many different species of mosquitoes are found in tropical, subtropical, and temperate zones. Three genera are of interest to us because they are involved in the transmission of disease. Culex is a carrier of bird malaria, one variety of Anopheles carries malaria, and Stegomyia (Aëdes) carries yellow fever. The life cycle of Culex will be described as a general example of the group.

Life cycle of Culex. The females lay their eggs in masses on still water. The water may be in an empty can, a barrel, a pond, or a lake. The eggs hatch to form larvæ that are commonly known as "wrigglers." These larvæ swim about actively, eat, and grow. They have breathing tubes attached near the posterior ends of their bodies, and periodically they come to the surface of the water to breathe. The larvæ eventually form pupal cases, and float upon the surface of the water while in the pupal condition. The pupæ can move about, but do not seek food.

After about seven days the adults emerge from the pupal cases, upon which they rest for a short time until their wings become dry. Quiet water is essential; otherwise the emerging adults in all probability would be washed off the pupal cases and would drown.

Types of mosquitoes. The larvæ of Anopheles do not have the breathing tubes found on the larvæ of Culex, and they usually lie in a horizontal position just beneath the surface of the water. The adults of the three genera also are easily distinguishable. Culex rests with the body parallel to the surface, while Anopheles has spotted wings and rests with its body pointed downward toward the surface upon which it is found. Stegomyia has white bands across its legs and abdomen and a white pattern resembling a lyre (musical instrument) on the head and thorax.

Malaria. For a great many years malaria was associated with swamps, and mistakenly thought to be brought on by breathing swamp "vapors," and especially "night vapors." This is merely one of the many examples of superstitions that have developed in the absence of knowledge or tested facts. In 1880 the French physician, Laveran, discovered Plasmodium, the malaria parasite.

Cinchona bark had been introduced into Europe and used in the treatment of malaria in 1640. Quinine was first isolated from cinchona in 1820. The English army physician, Major Ronald Ross, associated mosquitoes with malaria in 1898. Later discoveries showed that only the female Anopheles[1] bites and infects man, a true case of the female being more deadly than the male.

The Anopheles mosquito obtains the germs of malaria while sucking the blood of an infected person. These germs reproduce and become more numerous in the stomach of the mosquito, and then may be transmitted to the blood of a human being. In the blood of man the parasites enter the red corpuscles. Each parasite now grows and divides to form a number of sporozoites. The sporozoites break out of the corpuscles in which they were developed, and incidentally liberate a quantity of their waste product, called melanin. The presence of melanin in the blood stream produces the characteristic chill of malaria. Quinine does not always kill the malaria parasite, but keeps it from reproducing in the blood. This, of course, checks the disease.

Culex is often called a nonmalarial mosquito, presumably because the type of malaria it transmits does not affect man.

Yellow fever. Yellow fever is a disease apparently due to the presence of a filtrable virus (see page 495) in the blood. Noguchi isolated Leptospira in 1919, classified it as a spirochete, and for a time it was thought to be the organism of yellow fever. However, it now appears that Leptospira is responsible for another disease, whose symptoms are very similar to those of yellow fever.[2]

During the Spanish-American War a group of physicians, Reed, Carrol, Lazear, and Agramonte, were sent to Cuba to study the disease and the possibilities of prevention. They suspected mosquitoes of being the carriers of the disease and allowed themselves to be bitten, as a result of which experiment Lazear died. They established their hypothesis as a fact, however, and now it is known that yellow fever is transmitted

[1] It has now been established that there are several varieties of the Anopheles mosquito. Apparently only one of these varieties is involved in the transmission of malaria.

[2] Hemorrhagic jaundice, also transmitted by a mosquito.

by the mosquito Stegomyia. It should be noted that before a Stegomyia mosquito can transmit yellow fever to man, it must itself become infected.

Control of mosquitoes. The prevention of malaria and yellow fever becomes, then, a matter of eliminating mosquitoes, for without mosquitoes there can be no transmission. The best way to eliminate mosquitoes is to do away with all possible breeding places. To do this effectively, the following measures should be observed:

1. Drain stagnant pools of water.
2. Dispose of all empty cans, barrels, etc., that may become filled with water during rains.
3. Place oil upon the surfaces of pools that cannot be drained. The oil spreads out over the surface of the water and prevents the mosquito larvæ from obtaining oxygen.
4. Encourage natural enemies, such as small fish which eat mosquito larvæ, and dragon flies, bats, swifts, flycatchers, and nighthawks which eat adult mosquitoes.

Large bodies of water having wave action and running streams need cause no concern, because, as already explained, mosquitoes cannot breed successfully in moving water. Since it is probably impossible entirely to eliminate mosquitoes, dwellings in the tropics and subtropics should be screened. In general, every effort should be made to avoid being bitten.

When the United States undertook the building of the Panama Canal, one of the first steps in the work was to eliminate mosquitoes in so far as possible. Undoubtedly this was an important factor in insuring the success of the project. The French had previously tried to build a canal across Central America, and had failed, after suffering the ravages of yellow fever and malaria.

THE HOUSEFLY MAY CARRY A NUMBER OF DISEASE-PRODUCING ORGANISMS

Housefly. The housefly, Musca domestica, is another dangerous insect pest. Its presence is annoying, and in addition, it serves to carry the germs of typhoid fever, and probably bacteria that are associated with other diseases. This does not mean that every housefly is a carrier of germs, but the possibility always exists.

Housefly and bacteria. A housefly may carry bacteria in two ways. The bacteria may be eaten and later deposited in the excreta of the fly. Or the bacteria may become attached to the many hairs and bristles that cover the fly's body. These bacteria may drop off into food or water in the course of the fly's wanderings. An examination of a housefly's leg with the aid of a microscope will indicate how easily bacteria may become attached to the hairs and bristles.

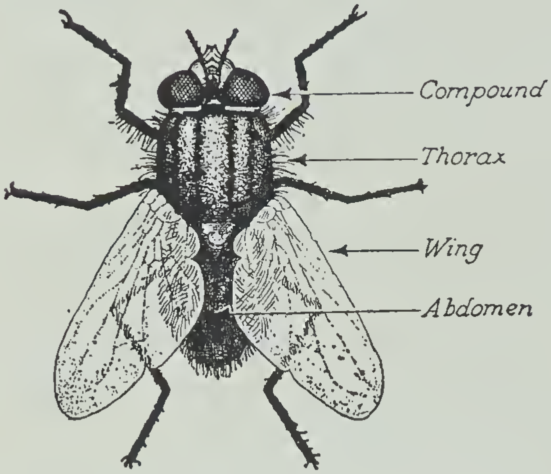

FIGURE 223. The housefly.

Life cycle of the housefly. The female housefly lays her oval, white eggs upon material which will serve as food for the larvæ. Such material may be decaying waste, decaying flesh, or decaying vegetable material. It has been claimed that ninety-eight per cent of all houseflies breed in horse manure. The female produces about two hundred and fifty eggs at one time, and will lay four to six masses of eggs during her lifetime. The eggs may hatch in one day under favorable conditions. The larvæ are called "maggots," and are whitish and wormlike in appearance. They feed upon decaying organic materials, grow rapidly, and are ready to become pupæ in six or seven days. They remain in the pupal cases for four or five days and then the adults emerge.

Rate of reproduction. The entire cycle from egg to sexually mature adult may occur within a period of three weeks. With this in mind, it is not hard to understand the enormous increase in the number of flies that may occur within a summer season. In general, the longer the warm season, the greater the possibilities for increase in numbers.

Control of the housefly. Warfare against the housefly has been carried on in a number of ways. The most effective measure, as in the case of mosquitoes, is to remove all possible breeding places. It is highly probable that there are fewer flies than formerly in many of the large cities because the automobile so largely has replaced the horse. But there is an abundance of flies in rural regions where horse manure is allowed to collect in piles about the stables. They may be eliminated to a large extent by removing the manure and spreading it upon the fields at frequent intervals. Dry manure does not supply a suitable breeding place for the housefly. Adult houseflies may be trapped or poisoned in a variety of ways, and various commercial devices are offered for such purposes. These methods are most effective when they are used early in the season.

SOME FLEAS CARRY BUBONIC PLAGUE

Fleas. Fleas are external parasites upon mammals and birds. There are a number of different species, including the human flea (Pulex irritans), the Indian rat flea (Xenopsylla cheopis), the European rat flea (Ceratophyllus fasciatus), and the dog flea (Ctenocephalus canis).

Life cycles of fleas. These species differ somewhat as to life cycles, but the following account will give a general idea of the facts. The eggs are laid on the body of the host and usually drop off to lie on the ground or the floor, as the case may be. The eggs hatch to produce larvæ within a few days. The larvæ feed upon bits of organic waste, which accumulate on a floor or on the ground together with dust and dirt. Pupæ are formed, and then the adults emerge. The adults must now find suitable hosts. The process of development may take no longer than two or three weeks, or it may be greatly lengthened if conditions of temperature and food supply are not favorable. Fleas appear to be favored by sandy soil and warm climate.

Rat fleas and bubonic plague. Rat fleas are distinctly injurious because they carry bubonic plague (see p. 494). Or it might be said that the rat and the flea are equally guilty. The fleas live on the infected rats, but occasionally bite man, and thus the disease is disseminated. Animals other than rats — ground squirrels, for instance — are sometimes involved in the spreading of bubonic plague, because they sometimes become the hosts of rat fleas. Many rat fleas do not transmit bubonic plague, because they themselves have not become infected.

Control of fleas. In case of plague epidemics one of the first measures is to destroy as many rats as possible. In one case, at least, it has become necessary to destroy the ground squirrels. Another measure is to destroy all fleas which have entered dwelling places. Fumigation of houses and buildings is effective in killing fleas, but because of the danger to human life, the work must be done by an expert. Household pets may be relieved of fleas by washing them in diluted stock dip or a diluted solution of kerosene, soap, and water.

SOME LICE ARE ASSOCIATED WITH DISEASE TRANSMISSION

Lice. Lice are wingless, parasitic insects, having piercing, suctorial mouth parts. They live by sucking blood. Two types of lice that often attack man are the body louse (Pediculus humanus corporis) and the head louse (P.h. humanus). Body lice live largely in the clothing, laying their eggs in the seams thereof. Head lice live in the hair, to which they attach their eggs. Both varieties are likely to flourish among people who do not live under sanitary conditions.

Lice and disease transmission. Lice are very dangerous little parasites because they are able to transmit diseases. Apparently such diseases include typhus, relapsing, and trench fever, and probably tularemia. Lice have long been a common pest in armies. When a great many men live closely together there is every opportunity to spread them about. They may be controlled by boiling clothing, and by using medicated washing solutions. The soldiers of the World War used to refer to these unwelcome insects as "cooties" and "seam squirrels."

Summary. We may summarize the foregoing facts by again noting that among the many species of insects are some which are associated with disease transmission. Among the diseases involved are malaria, yellow fever, typhoid fever, bubonic plague, and typhus fever. In this discussion only the more important and better-known cases have been mentioned. Other species of insects may also be involved in disease transmission. Tsetse flies, for instance, transmit sleeping sickness. It is reported that other biting flies may transmit this disease. Bedbugs have been suspected of being involved in the transmission of some tropical diseases.

SUGGESTED ACTIVITIES

Scientific methods

A biologist learns to control organisms by studying their habits, structures, natural enemies, and life histories.

1. With the aid of the microscope or microprojector, examine a slide bearing the mouth parts of a mosquito. Observe the sucking tube, and the piercing structures.
2. After consulting the reading references at the end of this chapter, prepare a report upon the life cycles of mosquitoes.
3. Read and report upon the story of how the transmission of yellow fever was traced to the mosquito Stegomyia.
4. Investigate the report upon the "Conquest of the Canal Zone" by the United States Government.
5. With the aid of a microscope or microprojector, examine the leg of a housefly. Does it suggest the possibility that the housefly may carry germs from place to place?
6. Place a piece of meat in a battery jar and allow it to decay. Make it accessible to flies so that eggs may be laid upon the meat. After the eggs have been laid, keep the battery jar loosely covered, and in a warm place. Observe the successive development of larvæ, pupæ, and adult flies. Fruit flies also multiply rapidly upon decaying bananas when placed in wide-mouthed bottles loosely stoppered with cotton.
7. After looking up the references listed under the heading, Books to Read, at the end of this chapter, prepare a report on the control of houseflies.
8. With the aid of a microscope or microprojector, examine a slide bearing a flea. Study the external structures of this animal. What adaptations for life as an external parasite are exhibited? Make a similar examination of slides bearing lice.
9. Prepare a table of four vertical columns which include the following information: (*a*) insect, (*b*) disease carried or transmitted, (*c*) life history of the insect, and (*d*) methods of control. Tabulate these data for Anopheles, Stegomyia, the housefly, the Indian rat flea, human lice, and tsetse flies.

SUMMARY OF PRINCIPLES

1. Insects constitute the largest class of organisms (number of described species).
2. Three causes are chiefly responsible for the success of insects, namely: they are adaptive, they reproduce rapidly, and they are small in size.
3. Insects affect man as carriers of disease and as competitors for food.
4. Two genera of mosquitoes have considerable importance: Anopheles, which transmits malaria, and Stegomyia, which transmits yellow fever.
5. Malaria and yellow fever may be controlled by destroying breeding places of the mosquitoes that transmit these diseases.
6. The housefly may transmit several human diseases, including typhoid fever.
7. The eggs of houseflies are usually laid in decaying organic materials — manure in particular. Control of the housefly is possible through destruction of its breeding places.
8. Rat fleas may carry bubonic plague, which may be controlled by destroying the rats that act as hosts for the fleas.
9. Lice are associated with disease transmission (typhus fever and relapsing fever).

GUIDE QUESTIONS

1. What are the reasons for the success of insects as a group?
2. Discuss two general ways in which insects may affect the welfare of man.
3. Name five insects that carry disease and state the disease carried by each.
4. Describe several procedures to be followed in controlling mosquitoes.
5. How can the Anopheles and Culex mosquitoes be distinguished from each other: (*a*) as adults, (*b*) as larvæ?
6. Explain the reason for the former belief that malaria was caused by breathing swamp vapors.
7. Does the male or female Anopheles transmit malaria?
8. What are some dangers resulting from the presence of the housefly?
9. How may the housefly be controlled?
10. Describe the life history of the housefly.
11. Explain the relationship between the house rat and bubonic plague.
12. What are the dangers resulting from the presence of lice?

BOOKS TO READ

Fernald, H. T. *Applied Entomology.*
Fitzpatrick, F. L. *The Control of Organisms.*
Haggard, H. W. *The Science of Health and Disease.*
Hegner, R. W. *Practical Zoology.*
Metcalf, Z. P. *A Textbook of Economic Zoology.*
Reese, A. M. *Outlines of Economic Zoology.*
Weed, C. M. *Insect Ways.*

CHAPTER XXXIV

INSECTS AND THE FOOD SUPPLY

Problems:

1. What kinds of insects destroy food materials, and how may such insects be controlled?
2. What kinds of insects are useful to man?

Foreword. We have learned that some insects are of importance to man because they may carry or transmit diseases. There are many other ways in which these small animals affect human welfare. In some parts of the world insects are commonly used as human food. Certain small species of bugs, grasshoppers, and the larvæ of beetles are eaten by some peoples. Some insects produce substances, such as honey, that are eaten by man. On the other hand, many species of insects feed upon materials that man might otherwise use as food for himself and for his domesticated animals. In this discussion we shall be concerned with *some* of the more important kinds of insects that have relationships to the food supply.

MANY INSECTS DESTROY FOOD MATERIALS

Termites. Termites or "white ants" are included among the injurious insects. It should be noted that these animals really are not ants, but the designation "white ants" has become quite common. There are a number of species and the group is most common in the tropics and subtropics. However, some termites do appear even in temperate zones.

Termites live in social groups. They develop "castes" or different types of individuals. These include females, males, soldiers, and workers. The workers are the most numerous type. Termites build extensive galleries by tunneling in wood and other materials.[1] Such tunnels may be constructed in the wooden

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[1] The greatest damage done by termites does not pertain to the destruction of food materials. However, some species attack the roots of certain cultivated plants.

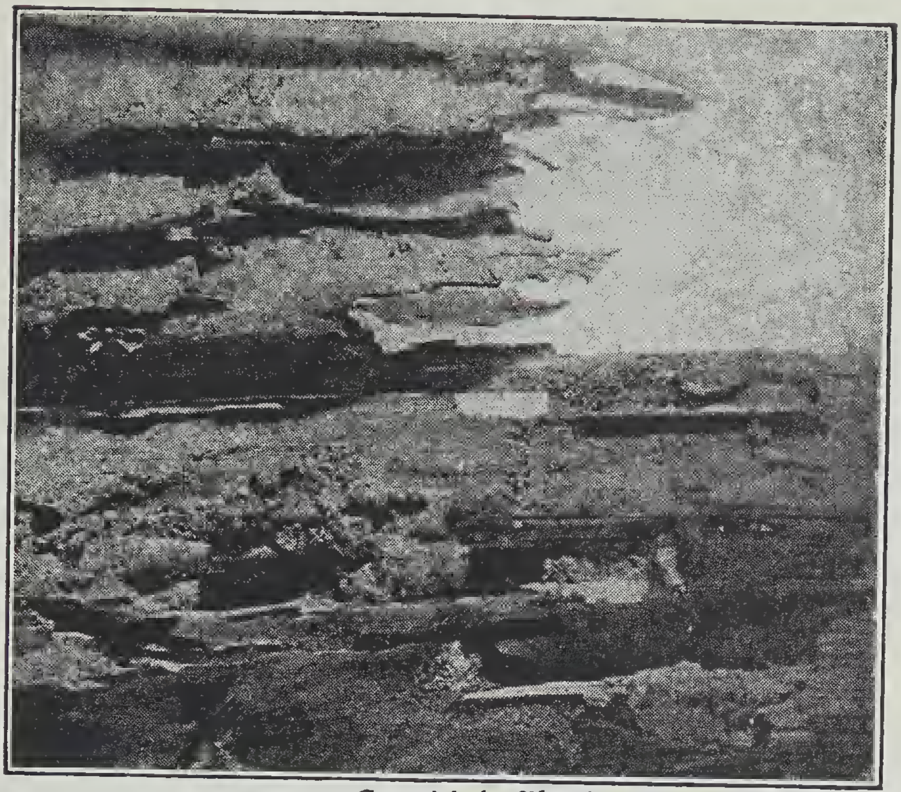

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FIGURE 224. A piece of wood that has been attacked by termites.

floors or walls of buildings. The presence of the termites often is not suspected for some time. Meanwhile, they may do considerable damage. The first definite sign of their presence may be the collapse of a wall or a floor.

Control of termites. Buildings may be protected against termites by constructing foundations and lower floors of concrete, brick, or stone. A fair measure of protection is sometimes secured by soaking in creosote all timbers which will be in contact with the soil.

Cockroaches. Cockroaches are familiar to most people who live in cities. Four species are commonly found in the United States and other parts of the world. The female cockroach develops an egg case, which remains attached to her abdomen. The eggs are deposited in this case and are carried about by the female until they hatch.

Cockroaches undergo incomplete metamorphosis. At first the young roaches have no wings or reproductory organs. Under favorable conditions, they may become adults after six-months' time. Otherwise, the young may not become adults until five years have passed.

Habits of cockroaches. Roaches frequent kitchens and pantries in the home. Their flattened form enables them to take refuge in many cracks and crevices. They usually emerge to seek food during the hours of darkness. They eat many kinds of food materials and may injure many kinds of stored goods. The fact that they have an unpleasant odor makes them even more undesirable.

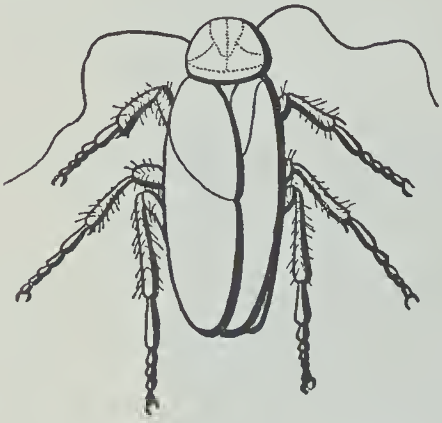

FIGURE 225. A cockroach.

Control of cockroaches. Cockroaches rarely eat poisoned baits. They may be killed by fumigation (poison gas), but this is not practicable in many cases. The fumigating must be done by an expert because of the danger to human life. Poison powders distributed where the roaches take refuge are fairly effective in destroying them. Small amounts of such powders usually are only mildly poisonous, but care must be taken to keep small children out of danger.

Grasshoppers. Grasshoppers eat such forage crops as grasses and alfalfa. They also attack many other cultivated plants, including corn, sorghum, soybeans, cowpeas, rye, oats, and wheat. The damage done may be unnoticed if the grasshoppers are not too numerous. However, these insects sometimes become so common that "locust plagues" result. The grasshoppers eat all of the green plant materials available, and then begin to migrate across the country, destroying crops as they go. Such plagues of grasshoppers occurred in some of the western states in the period between 1770 and 1790. Severe damage to crops, occasioned by grasshoppers occurred in some western states in 1931. Once a migration has begun, it is likely to continue until the grasshoppers are killed by natural enemies or by cold weather. "Swarms" of grasshoppers have been sighted at sea on some occasions. Successive dry seasons are likely to be accompanied by an increase in the numbers of grasshoppers.

Grasshoppers as food. It should be noted, however, that grasshoppers have their beneficial aspects. They are used as human food in parts of the tropics or subtropics, where the natives make a practice of eating not only grasshoppers, but other insects and insect larvæ as well. For instance, grasshoppers are sold as food in the Philippine Islands. Ordinarily, their legs are removed and they are roasted before being eaten.

Aphids or plant lice. Aphids or "plant lice" are true bugs,[1] and the word "lice" is a misnomer. All of them are relatively small in size. They have mouth parts adapted for sucking the sap of plants. The plants are injured by the loss of sap, seriously so if the aphids are numerous. Aphids secrete a sticky material which tends to protect them from some of their natural enemies. In some cases they secrete a material called "honeydew." Honeydew contains sugar, and is eaten by ants. Some species of ants protect and care for the aphids from which they obtain this honeydew.

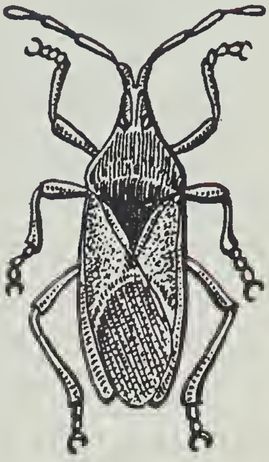

FIGURE 226. A squash bug. One of the many species of insect pests.

Damage caused by aphids. There are many species of aphids, and they attack a variety of plants, ranging from weeds to garden flowers, fruit trees, and the like. The corn-root aphis is a species that is cared for by ants. The ants distribute these aphids to the roots of corn plants in the early summer. The ants profit to the extent that they obtain honeydew from the aphids. The aphids may cause serious damage to the corn, especially if they are present in large numbers.

Scale insects. Scale insects also are true bugs. There are numerous species of these scale insects, having widespread geographical distribution. They are usually small in size, and many species are permanently attached to plants when in the adult condition. They develop a secretion which forms the protective scale or covering.

Habits of scale insects. Some scale insects live on leaves, some on fruits, some on stems, and some on bark. They suck the sap of the host plants, after the fashion of aphids. If the scale insects are sufficiently numerous, trees or other plants may be killed and fruit rendered unfit for commercial uses. Scale insects have been a menace to the citrus-fruit (oranges, lemons, etc.) industry.

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[1] Bugs are members of the order Hempitera.

Control of aphids and scale insects. Various sprays have been developed to kill aphids and scale insects. The work of control is complicated by the fact that scale insects are protected against some sprays by their scales. Certain insects have proved to be valuable because they prey upon scale insects. Such insects include certain ladybird beetles and lacewing flies.

Useful scale insects. Some scale insects, not found in North America, are useful. One North-African species is gathered by the natives and used as food. Some Asiatic species are used in making dyes, wax, medicines, and shellac.

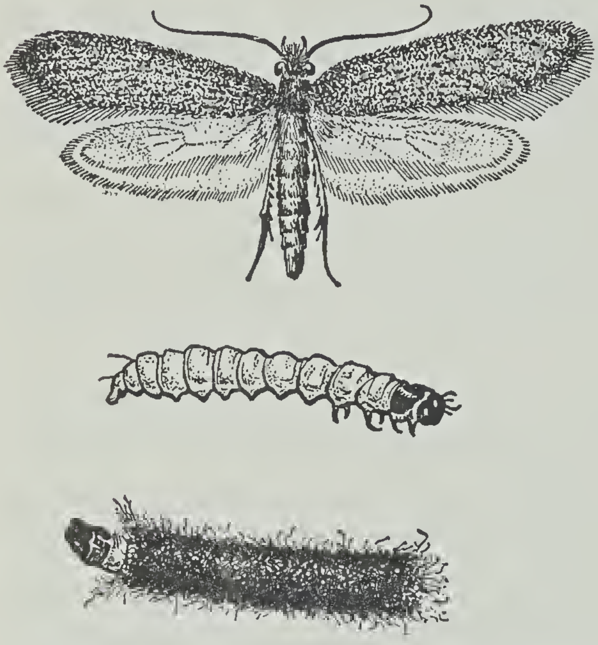


FIGURE 227. Stages in the life cycle of a clothes moth. Which form feeds upon wool? Which one lays the eggs? How is this pest controlled?

Clothes moths. The larvæ of clothes moths attack woolen materials, leather, feathers, hair, and fur.[1] Three species of these moths are found in the United States. They may continue to reproduce throughout the year, as long as they are indoors.

Adult clothes moths often lay their eggs on materials that will serve as food for the larvæ. We usually become aware that clothes moths are in the home when we see the small adults flying about. Unfortunately, such adults may have come from larvæ that have already destroyed clothing or upholstered furniture. For the actual damage is done by the larvæ. The larval stage may last as long as two years. Under favorable conditions, however, the larvæ develop into pupæ after a much shorter time.

[1] Most of the materials destroyed would not be considered "foods."

Control of clothes moths. Clothing in constant use is not likely to suffer from the attacks of clothes-moth larvæ. It is best to store clothing in mothproof containers, but it should be well-brushed before this is done. The brushing will remove any clothes-moth eggs or larvæ that may be present. Clothing in cold storage is protected by low temperatures. The most effective method to use in killing all clothes moths in a building is to *fumigate.* This, however, should be attempted only by an expert.

European corn borer. The European corn borer is the larva of a moth that was introduced into the United States in or about 1910. By 1930 this species had spread westward almost to the Mississippi River. A number of state and federal agencies have been at work during the past few years in an attempt to check the spreading of this pest.

European corn-borer larvæ may center their attacks upon corn. However, they also feed upon many other cultivated plants, including some flowers. They eat leaves, bore into stems, and even penetrate the ears of corn. Two generations of adults are produced each year, and the second generation of larvæ spend the winter in the stalks and stems of plants. One method that aids in controlling them is to destroy all crop refuse, such as stalks and stems, during the fall or early winter.

The codling moth. One of the most important insect enemies of apples is the codling moth. This insect passes the winter in the larval condition. The larvæ are protected by small cocoons. Fortunately a good many of the larvae are destroyed by birds. Early in the spring the larvæ that have survived the winter develop into pupæ and then into adults. The adults appear at just about the time that apple leaves are forming, and lay their eggs upon these leaves. The eggs hatch at about the time that the apple trees are in bloom. The larvæ enter the blossoms and the fruits that are being developed. Thus there is little outward indication that the young fruit is infested, for the larvæ have been present almost from the beginning of development. When the larvæ are full-grown, they bore out of the fruit, and it is then that we become aware of their presence.

Control of the codling moth. The presence of codling-moth larvæ or "worms" in apples causes the apples to decay, to ripen too quickly, and to drop from the trees. Ninety per cent of the fruit may be injured. Poison sprays are used to destroy codling-moth larvæ with fairly good effect. They should be employed at the time that the trees are in blossom.

The gypsy moth. The gypsy moth is not a native species, but was introduced from Europe in 1869. It was soon recognized as being a serious pest, and every effort has been made to prevent its dissemination over the country. At present, it is restricted to the New-England region. The larvæ of the gypsy moth are leaf-eaters. They attack apple trees and shade trees, and if sufficiently numerous may destroy all of the leaves. This destruction of leaves often results in the death of the trees.

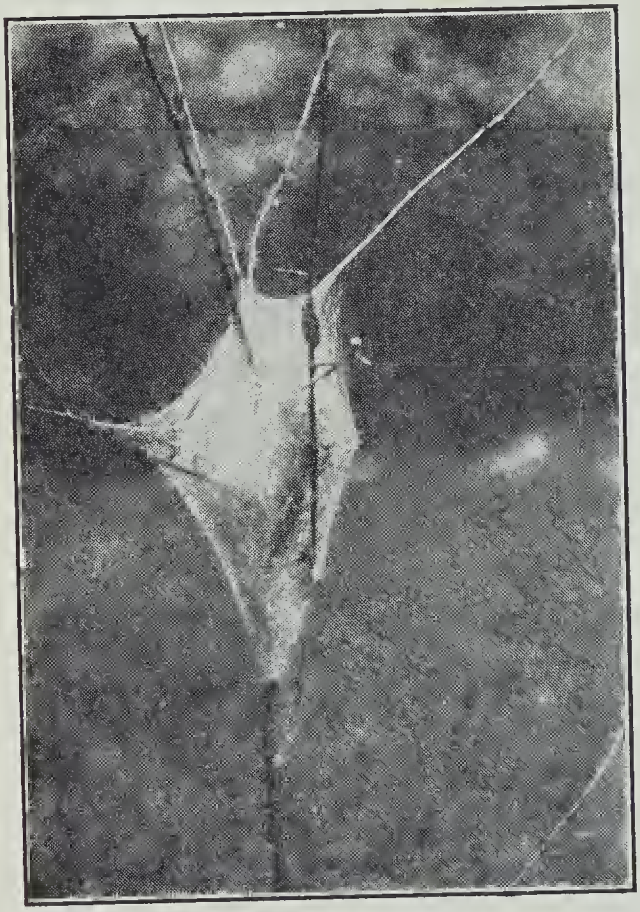


FIGURE 228. "Nest" made by larvæ of tent caterpillars. The larvæ leave the nest to feed upon the leaves of the young tree.

The brown-tail moth. Another introduced pest is the brown-tail moth, which arrived in the United States in 1897, or perhaps a short time before. It is also found in the New-England region, and its larvæ eat the leaves of trees. The larvæ of this species are covered with hairs. These hairs are carried about by the wind. They get into houses and clothing, and when they become embedded in the human skin they produce a severe irritation known as "brown-tail rash."

The further dissemination of gypsy moths and brown-tail moths is being prevented by quarantine measures. Sprays are used to kill the larvae, and natural enemies have been introduced into the infested regions.

Tent caterpillars. Tent caterpillars are larvae produced by some of our native moths. These larvae have the interesting habit of building "nests" or "tents." (See Figure 228). They eat the leaves of apple, wild cherry, plum, peach, walnut, poplar, willow, and some other trees. When not feeding, the larvae take refuge in their "nest." The writer observed one case in which these caterpillars had stripped the leaves from almost every tree in a large valley. Repeated loss of leaves eventually causes the death of trees.

Ants. There are many different kinds of ants in various parts of the world. Perhaps these insects are best represented in tropical countries, where some types are large in size, and are used as food by native tribesmen. Like termites, ants tend to live in colonies. Such colonies usually include females (one or more), a number of males, and workers. Generally the workers are the largest group. Some ants build their colonial houses or "nests" underground. Other species erect their dwelling places above the surface of the soil, or live in trees, stumps, and logs.

Many of the ants are among our worst insect pests. A good example is the Argentine ant, which has evidently reached this land in shipments of goods from South America. It has become very common in parts of the South and Southwest. The Argentine ant eats almost anything of plant or animal origin, and is a pest both out of doors, and in homes. It has even been known to attack sleeping children.

Other native species of ants frequently work their way into houses, and particularly kitchens. They are likely to be a great nuisance because they get into foods, and destroy or injure other materials. Some of the small varieties are very difficult to control because they can enter through such tiny cracks and crevices. Nor are the destructive activities of ants limited to homes. Many of them are pests of field and garden, largely because they protect and care for aphids and scale insects. Apparently they do this because they want to get the sugary honey dew that is secreted by these small bugs.

Control of Ants. Ants are naturally among the insects that we wish to suppress. The best approach to the problem is to destroy their communal homes whenever this is possible. Sometimes such colonies can be broken up by pouring hot, soapy water on them. Oil may be used in the same way, but is not suitable indoors, and will destroy the grass of lawns.

SOME INSECTS ARE USEFUL TO MAN

The honeybee. For centuries man has obtained honey from the honeybee. The supply was obtained first from the "wild" bees, which usually developed their colonies in hollow trees. Then the raising of "tame" bees was developed as an industry. The so-called "wild" swarms are still to be found in timbered areas, but in many cases they are escaped "tame" bees.

Bee colonies. Bees have a complex social life. They develop the following types of individuals:

1. *Females* (queens): usually one to each colony. The queen is developed from a fertilized egg that has been kept in a special, large, queen cell. When the larva hatches from this egg, it is raised on a diet of "bee jelly."
2. *Males* (drones): usually a number to each colony. They are developed from unfertilized eggs. Drones are of no value to the colony, except that they fertilize the female. The workers generally kill the drones at the end of the warm season.
3. *Workers:* make up the bulk of the colony. Like females, they are developed from fertilized eggs, but the eggs are deposited in ordinary cells, and the larvæ that hatch from them are raised on a diet of "bee jelly," honey, and pollen. Workers care for the eggs and young, collect food, and do other necessary work. Honey and pollen are, of course, obtained from flowers.

The female or queen is the central figure around which the honeybee colony is organized. When two or more queens are present at the same time, the phenomenon known as "swarming" usually occurs. There sometimes is a certain amount of fighting, and the extra queens may be killed. Otherwise, the extra queen or queens may be driven out of the parent colony, each accompanied by a "swarm" of workers and drones. The swarms then seek new locations in which to establish colonies.

Bee raising is well established as an industry in the United States. Many people in the Rocky-Mountain region and on the Pacific Slope have begun to raise bees. Bees are able to find food even in semiarid or very dry climates.

Ichneumon flies. The ichneumon flies belong to the same general group of insects as do the bees, but are useful to man for an entirely different reason. Ichneumon flies are beneficial because they are parasitic upon the larvæ of a number of undesirable insects, including some species of moths, butterflies, and beetles. The adult female ichneumon fly lays her eggs on the bodies of the hosts that are to serve as food for the larval ichneumon flies. The larval ichneumon flies literally eat the hosts, and many of the latter are killed.

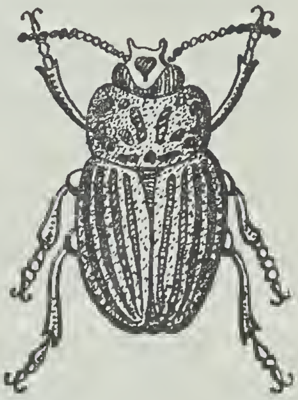


FIGURE 229. A potato beetle — an insect pest.

Ladybird beetles. The ladybird beetles also are numbered among the useful insects. Many species of ladybird beetles destroy the injurious scale insects and aphids. One species in particular has become famous. This is the Australian ladybird beetle, which was brought to the United States, and California in particular, to act as a natural check upon the increase of the cottony cushion scale.

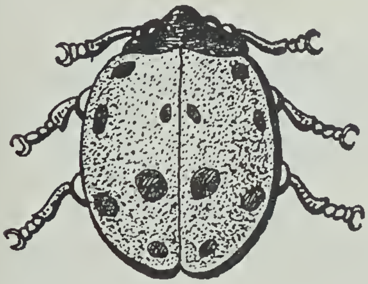


FIGURE 230. A ladybird beetle. Is this type of insect beneficial or harmful? Explain.

Silkworms. The silkworms are larvæ of moths that spin silken cocoons from which silk thread is obtained. Each cocoon contains some twenty-five hundred feet of silken thread. The larvæ eat mulberry leaves for the most part, and these must be available if the larvæ are to develop successfully. When the larvæ have spun their cocoons in which they pass through the pupal stage, they are killed by heating them. If they were allowed to complete their development, the silk threads of the cocoon would be cut and broken when the adults emerged. A certain number of pupæ are allowed to complete their development in order that there may be adults to produce the next generation of larvæ.

Most of the world's supply of raw silk is produced in China and Japan, and then shipped to the United States to be manufactured into silk fabrics. Silkworms can be raised successfully in other countries, but the work involves a considerable amount of hand labor, which is available at low cost in the Orient.

Summary. In the preceding chapter we learned that some insects are associated with the transmission of diseases. In this chapter we find that many other species of insects affect the welfare of man for a variety of reasons. Some species are injurious, others are beneficial. Among the injurious activities we may include the destruction of wood (by termites), the destruction of stored food and other materials, and attacks upon crop plants and forest trees. Honeybees and silkworms, on the other hand, are definitely beneficial. So are ichneumon flies, ladybird beetles, and other species which prey upon the undesirable insects.

SUGGESTED ACTIVITIES

Scientific methods

A scientist keeps tabulated data (facts about organisms) for ready reference.

1. Examine mounted specimens which illustrate the life cycles of various types of insects, such as termites, grasshoppers, cockroaches, clothes moths, and the cabbage butterfly.
2. With the aid of a microscope, compare the chewing mouth parts of a grasshopper with the suctorial (sucking) mouth parts of a housefly, and the suctorial mouth parts of a mosquito.
3. Collect and mount specimens which represent different stages in the life cycle of some insect. Label and describe each stage.
4. After consulting the reading references at the end of this chapter, prepare a report upon the importance and control of scale insects.
5. After consulting the reading references at the end of this chapter, prepare a report upon communal life as exhibited by (*a*) ants, or (*b*) honeybees.

6. Prepare a table in which are listed the insects discussed in this chapter. In a second column indicate the economic importance of each type. In a third column indicate means of control, if control is desirable.

SUMMARY OF PRINCIPLES

1. Many insects compete with man for the food supply.
2. Some insects are of direct or indirect use to man.
3. Termites are among the undesirable insects because they destroy wood and other materials.
4. Cockroaches are household pests, which may be controlled by cleanliness in kitchens and through the use of certain poison powders.
5. Grasshoppers destroy crop plants.
6. Aphids and scale insects destroy or injure plants by sucking their juices.
7. Partial control of aphids and scale insects is obtained by using poison sprays or by encouraging such natural enemies as ladybird beetles.
8. Clothes moths are insects whose larvæ destroy woolen clothing and other materials of animal origin.
9. The European corn borer, the codling moth, the gypsy moth, the brown-tail moth, and tent caterpillars are destroyers of various desirable plants.
10. Ants, bees, and termites are communal animals which exhibit division of labor among individuals of their social groups.
11. Honeybees, silkworm moths, ichneumon flies, ladybird beetles, and some other insects are useful to man, either directly or indirectly.

GUIDE QUESTIONS

1. Discuss four insects that are household pests.
2. Discuss five insects that are harmful to crops.
3. Discuss three insects that attack trees.
4. Discuss the development of social life among termites, ants, and bees.
5. Describe methods of controlling cockroaches.
6. Describe the relationships of aphids to: (*a*) ants, and (*b*) ladybird beetles.
7. What devices may be used to protect stored clothing from clothes moths?
8. What insects may be controlled by fumigation?
9. Why are ichneumon flies said to be beneficial?
10. How may a poison dust serve to kill insects?

BOOKS TO READ

Fernald, H. T. *Applied Entomology.*
Fitzpatrick, F. L. *The Control of Organisms.*
Hegner, R. W. *Practical Zoology.*
Herrick, G. W. *Manual of Injurious Insects.*
Metcalf, Z. P. *Textbook of Economic Zoology.*
Palmer, E. L. *Moths and Butterflies.* Cornell Rural School Leaflet, vol. 19, no. 4.
Palmer, E. L. *Pests of Plants, Pets, and People.* Cornell Rural School Leaflet, vol. 18, no. 3.
Reese, A. M. *Outlines of Economic Zoology.*
Weed, C. M. *Insect Ways.*

CHAPTER XXXV

THE FISHES, AMPHIBIANS, AND REPTILES

Problems:

1. What species of fishes are of economic importance to man?
2. How do certain species of frogs and toads affect human welfare?
3. In what ways are reptiles of economic importance to man?

SOME VERTEBRATES ARE USEFUL TO MAN; OTHERS ARE COMPETITORS AND NATURAL ENEMIES

Foreword. In this chapter we shall consider the fishes, the amphibians, and the reptiles. Emphasis will be placed upon those species which have known uses, or which are known to be undesirable.

Our study of the invertebrates, especially the insects, has made it evident that much of our success in dealing with them has resulted from learning their habits, life histories, and structures. We thus have been able not only to compete successfully with them, but to utilize some of them in various ways.

Likewise vertebrates, no doubt looked upon by primitive man as including many natural enemies and competitors, are receiving attention at the present time as possible contributors to human welfare. We recognize, however, that some of them are prejudicial to man's best interests.

Importance of vertebrates. The vertebrates, including the fishes, amphibians, reptiles, birds, and mammals, are, for the most part, larger organisms than those that we have been studying in the preceding chapters. Some species are useful to man for several reasons:

1. They provide food materials.
2. They furnish extractives and raw materials of commerce, such as hides, oil, bones, glue, fertilizer, feathers, and similar substances.

3. They destroy objectionable or injurious organisms.
4. They are used as draft animals.

On the other hand, some species are injurious because:

1. They destroy valuable organisms.
2. They eat materials that are useful to man.
3. They are associated with the transmission of disease.

FISHES AND THEIR ALLIES

Sharks. Sharks are not bony fishes, as are the other types discussed in this chapter. Their skeletons are composed of cartilage. One species, the white shark (Carcharodon), is of interest because it is accused of being a "man-eater." This species is ordinarily found in the warmer seas and attains a length of forty feet. It is greatly feared by the native swimmers in tropical regions.

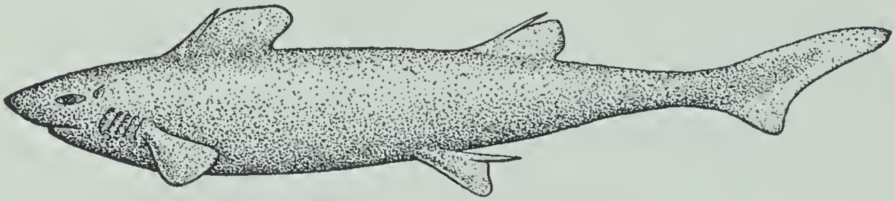


FIGURE 231. A shark.

The smaller species of sharks found in temperate and cold seas may be a nuisance to fishermen. The so-called dogfish sharks, which often are common in shallow water along the coasts, tear up nets with their sharp teeth. They also eat large numbers of food

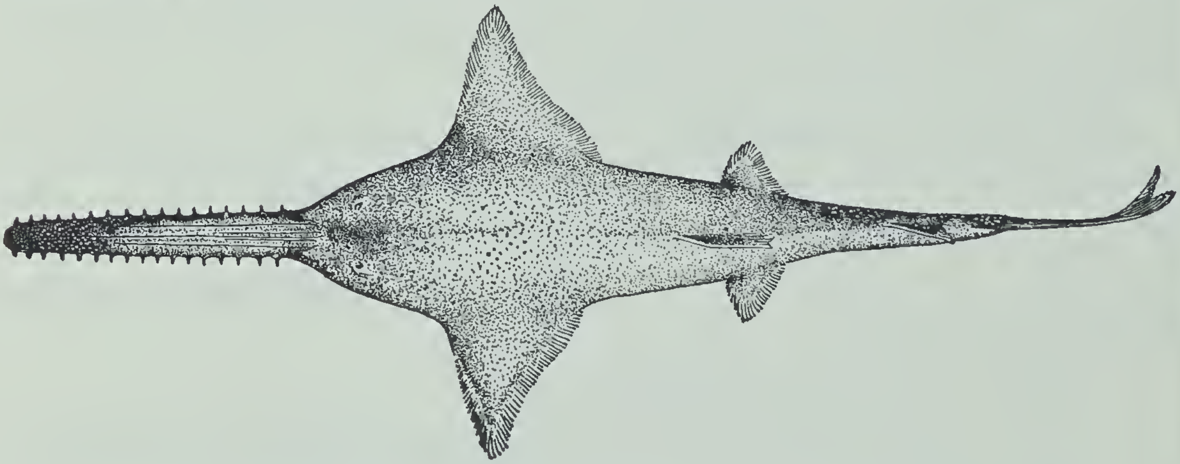


FIGURE 232. A sawfish This animal is a member of the shark and ray group.

fishes and drive schools of fish away from the shore. Sharks, however, are used as human food, especially in the Orient. Gelatin is obtained from their fins, oil from their livers, and their skins are dried and become the polishing substance known as "shagreen."

Herring. The herring is one of the more important marine food fishes. Schools of herring swim at or near the surface, and are sometimes composed of thousands of individuals. Herring sometimes enter bays, or even rivers. Female herring lay eggs both in the spring and in the fall. The young herring are often caught and canned as sardines. The larger herring may be salted and smoked, or eaten fresh.

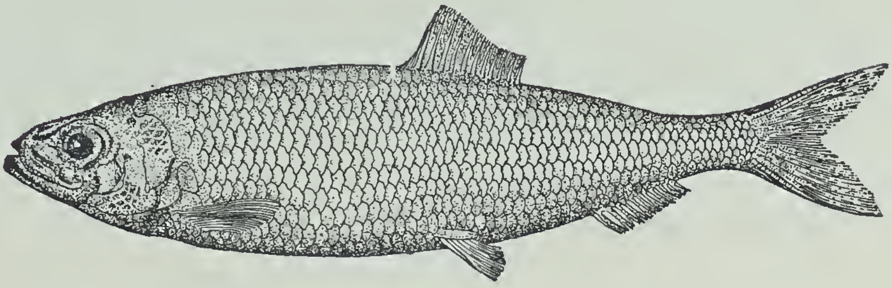


FIGURE 233. A herring.

Shad. The shad is another member of the herring family. The females of this species ascend fresh-water streams to lay their eggs. Young shad pass the early part of their lives in fresh water. Shad and their eggs (roe) are usually eaten fresh.

Codfish. The codfish is found in the North Atlantic and Arctic Oceans. It is a bottom feeder, found at depths as low as five hundred feet. Codfish are caught in nets, or with hand lines and trawl lines. The codfish is important as a food fish. In addition, the oil extracted from codfish livers has long served as a source of vitamin D.

Mackerel family. Flounders, halibut, and tunas are among the members of the mackerel family. These species are important as food fishes. Haliver oil is extracted from the livers of halibut. The flounders and halibut are characterized by their flattened forms. These fishes habitually lie near the bottom, with one *side* of the body directed upward, the other side downward. The side that is upward becomes darker than the side that is away from the source of light. Both eyes (in the adult) are located on the side that is directed toward the light.

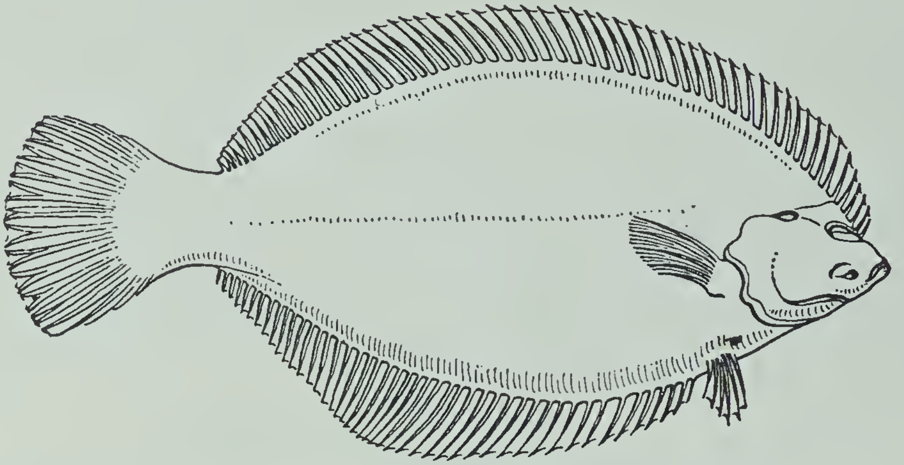


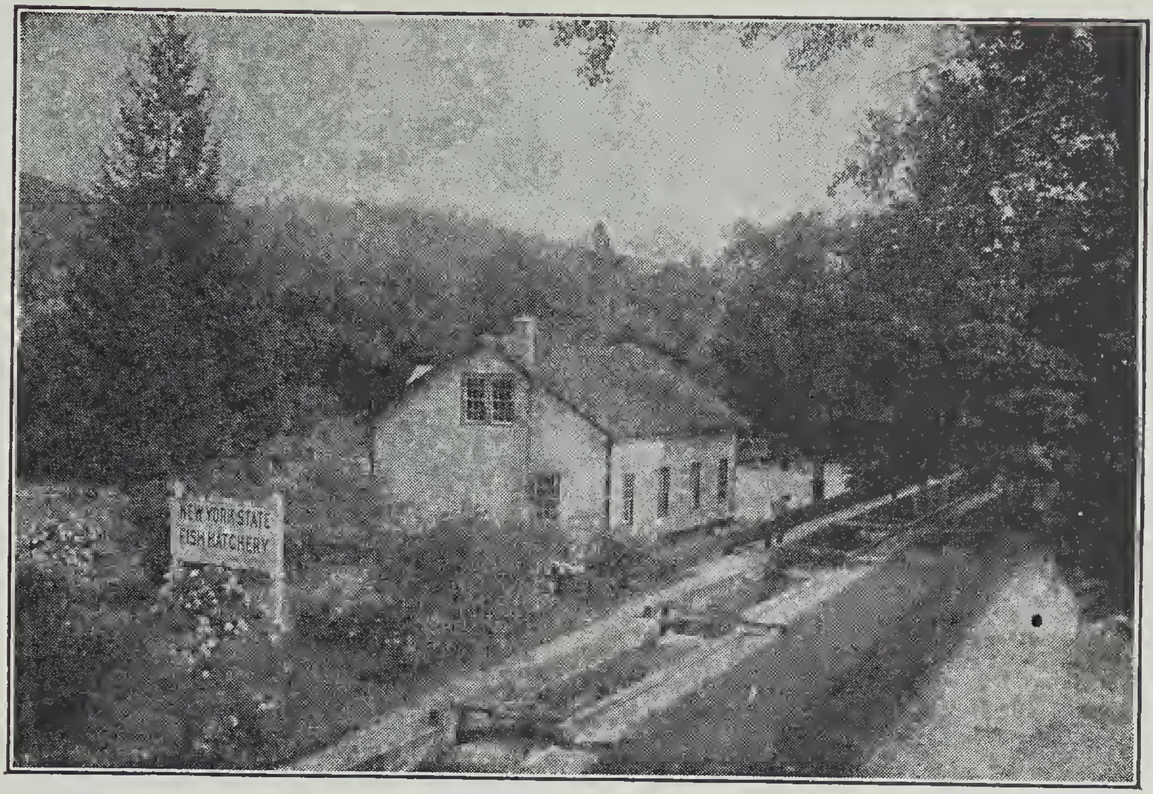
FIGURE 234. A flounder.

Salmon. Salmon are among the most important of the food fishes. Among the species found along the western coast of North America are the Chinook salmon and the red salmon. These species were used extensively as food by Indian tribes before the coming of the white men. They have become less numerous in recent years. A good deal of the commercial fishing is now confined to the bays along the North Pacific Coast.

Fish hatcheries. Extensive use of the salmon as food has led to an actual scarcity of these fish in some localities. A number of fish hatcheries in the Pacific-Coast region are attempting to raise large numbers of young salmon to be used in restocking the waters. Salmon eggs are hatched, and the young fish are protected until they are large enough to avoid many of the dangers that threaten the smaller individuals.

Sturgeons. Many fresh-water fishes are used as human food. The largest of the fresh-water fishes are to be found among the sturgeon group. Some sturgeons attain a length of ten feet. The eggs of the European sturgeons are used in making caviar, and the flesh also is eaten. Their large air bladders, when stretched out and dried, may be used as a substitute for window glass.

Catfish. The catfish group includes a number of fresh-water



Acme.

FIGURE 235. The New York State Fish Hatchery at Cold Spring Harbor.

species, among them the Mississippi catfish, the channel catfish, and the bullhead. These three types, as well as others, have been used extensively as human food. The result, in some localities, has been a great reduction in the natural supply. The Mississippi catfish is reported to attain a weight of about one hundred pounds; the other species are much smaller.

Trout. Another fresh-water group includes the lake trout, the brook trout, the mountain trout, the rainbow trout, and the whitefish. The lake trout and the whitefish are caught in commercial quantities. They also are quite large, attaining maximum weights of about one hundred, and seventy pounds respectively. The brook trout, mountain trout, and rainbow trout are smaller species, and are ordinarily protected from commercial exploitation by game laws. Trout fishing is a popular sport in localities where these fish occur. It has become necessary to supplement the natural supply in many places by restocking the waters with young fish that have been raised in fish hatcheries. Some species of trout are now raised for the market.

Acme.

FIGURE 236. Fishing in a mountain lake.

Pike. The walleyed pike (Stizostedion) and the yellow perch are important game and food fishes belonging to the same family. They are found in fresh-water streams and lakes. The less desirable pike or pickerel (Esox) is a member of another family, together with the muskellunge. The latter is one of the larger game fishes, reaching a weight of one hundred pounds.

Bass. Among the fresh-water game fishes are the small-mouthed bass, the large-mouthed bass, the rock bass, the crappie, and the sunfishes. All of these species belong to the same family and are regarded as good food and game fishes, although some of them are relatively small in size. Black-bass fishing, like trout fishing, is ranked as one of the finest sports.

Finally, one of the most important of the fresh-water families includes the carp, chubs, suckers, red horses, buffaloes, quillbacks, fresh-water mullets, and minnows. All of these fishes can be, and have been, eaten, but they have many small bones, and are not generally considered so desirable as the game fish previously mentioned. Minnows, of course, are utilized largely as bait in catching other fishes. This group is important because the various members eat other fishes, or serve as food for other fishes.

Carp. The introduced carp, for it is not a native species, first reached this country in about 1872. It has been very successful in its new environment, and has increased enormously. It is much more hardy than some native species, and can survive under comparatively adverse conditions. The carp eats sewage, plant materials, and various fresh-water animals including the young of other fishes. It stirs up a great deal of mud in the process of feeding, and this is often fatal to the well-being of desirable game fishes. The increase of carp in some lakes and streams has been accompanied by a decrease in the numbers of game fishes. Although the carp has not been the only factor that has operated to produce this result, its presence in our lakes and streams is doubtless unfavorable to the success of the game fishes and it is not considered a very desirable species. It is used as human food, but is not preferable to the native fishes which it tends to replace. It has one virtue in that it reproduces rapidly and so provides a large supply of food fish.

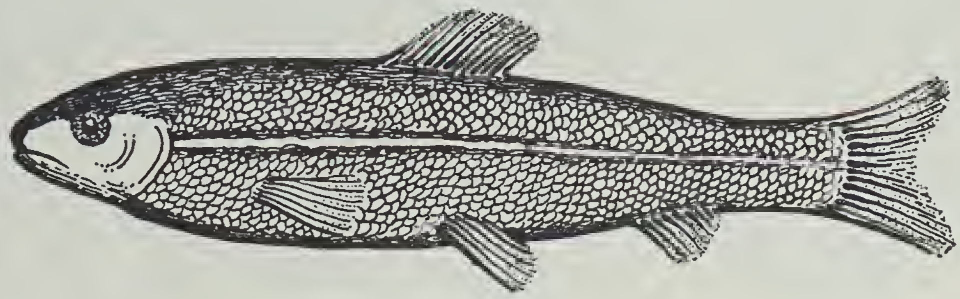


FIGURE 237. A minnow.

AMPHIBIANS

Amphibians. The amphibian group includes the frogs, toads, and salamanders. It is a relatively small group of vertebrates. All of its members are cold-blooded and have three-chambered hearts. The various species are aquatic or semiaquatic in habit. Ponds, marshes, and swamps are favored as habitats.

The so-called "mud puppy" (Necturus maculosus) is a member of the amphibian group. It is found in lakes, ponds, and streams.

It eats a good many of the smaller aquatic animals, and is probably undesirable for that reason.

Amblystoma. In general, the salamanders are useful animals because they are insect-eaters. One common species which has a wide distribution is Amblystoma tigrinum. This little animal lives in the water during the early part of its life, but later develops into an air-breathing adult. The adult lives in damp places of one kind or another, including cellars. Some people have a foolish fear of this salamander, believing it to be capable of inflicting dangerous bites. As a matter of fact, it is quite harmless.

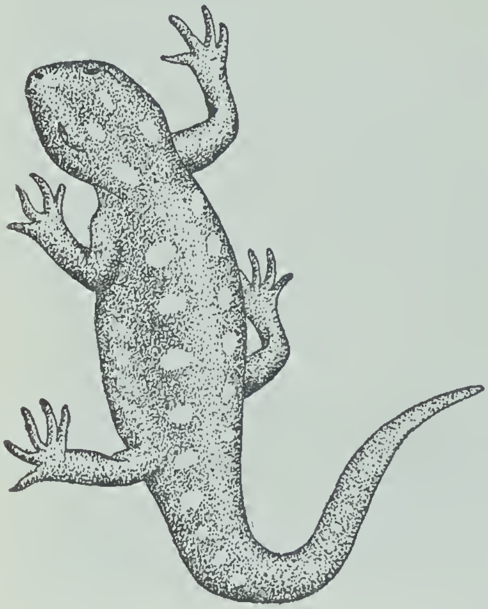
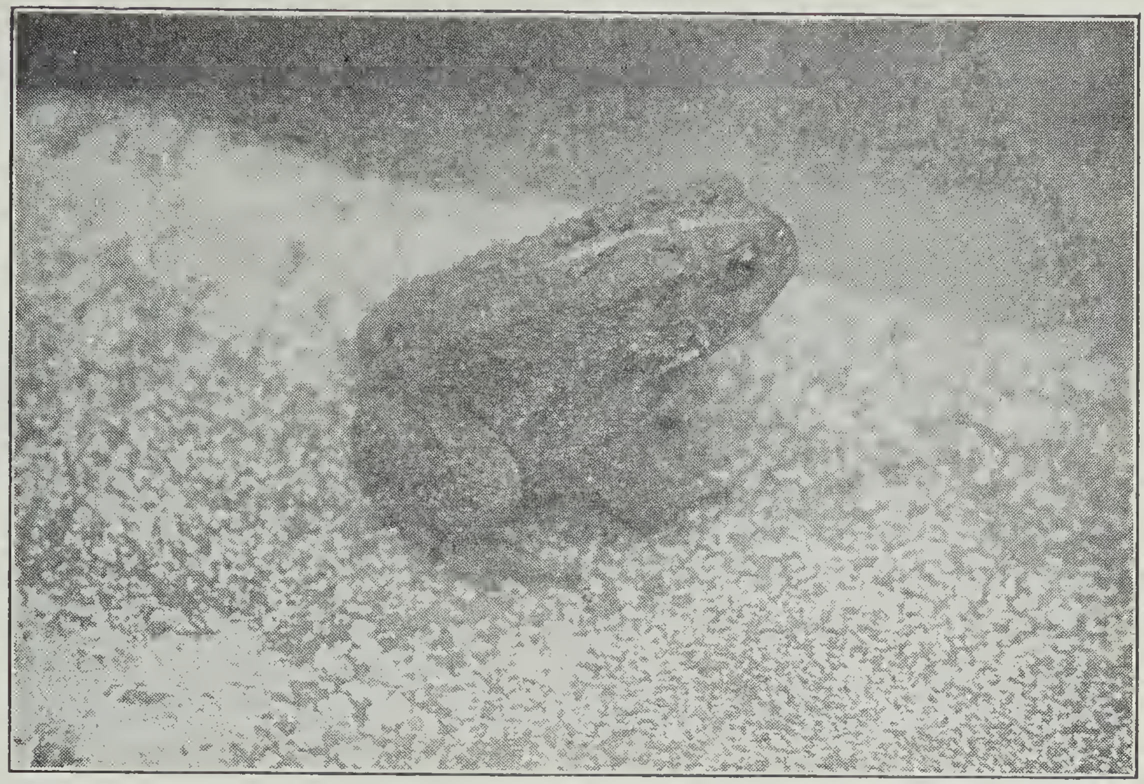


FIGURE 238. A salamander.

Toads. Toads are among the most valuable of our small animals. Adult toads are insect-eaters; they destroy many species of insects which are injurious to garden plants. The adult toads are nocturnal; that is, they come out to seek their food during the hours of darkness, but remain more or less inactive during the day. Some people having learned how valuable toads can be in the destruction of insect pests, even go so far as to collect toads and keep them in their gardens.

There has long been a superstition to the effect that human beings will develop warts on their hands if they handle toads. This story probably originated in the fact that the toad's skin is rough and warty in appearance. As a matter of fact handling toads will in no case cause human warts to develop.

The common North American toad passes through a life cycle similar to that of a frog. The eggs are laid in the water; when they hatch, tadpoles emerge. These tadpoles are fishlike in form and have gills, the latter enabling them to obtain oxygen from the water. As they feed and grow, limbs are developed. Finally, they undergo transformation from the tadpole to the adult stage. The tails and gills are absorbed and lungs are developed.



American Museum of Natural History, New York.

FIGURE 239. A toad. Some people believe that warts will grow on one's hands if toads are handled. Is this a superstition or a fact?

Unfortunately, toads have many enemies, including some species of snakes. The writer once came upon an unusually large number of snakes in the short grass bordering upon a shallow prairie pond. Snakes were not uncommon in the locality but such a gathering in one spot was puzzling. Upon reaching the pond, however, the reason became clear. The pond was full of toad tadpoles in the act of transforming into adults. They were crawling up out of the shallow water and upon the gently sloping beach. When they emerged they were easy victims for the snakes.

Frogs. Frogs likewise are beneficial because they are insect eaters. They also are used as human food, especially the larger species. Frog legs are considered a great delicacy, selling for as much as a dollar per pound. The most valuable species from the food standpoint is the large bullfrog. This species was formerly common in many parts of North America, but has become scarce in most localities because of persistent hunting. The smaller species of frogs are less valuable for food, but nevertheless should be protected because of their insect-eating habits. Frogs, like toads, are preyed upon by some species of snakes. But their worst enemies have probably been the market hunters and thoughtless small boys.

REPTILES

Reptiles. Reptiles, for some reason not quite clear, are often looked upon as being archenemies of mankind. This may be due to the stealthy, gliding movements of some snakes and lizards. Or it may be due to the fear bred by childhood stories about venomous snakes, gila monsters, man-eating crocodiles, or even the mythical sea serpents.

Importance of reptiles. Reptiles, as a group, are by no means man's worst enemies. Insects and bacteria interfere far more with human happiness and are harder to control. It must be admitted that many reptiles are not especially friendly. Now and then a boy will keep a turtle or a small alligator as a pet, but these animals can hardly be said to show any affection for their keepers.

Various species of reptiles are of use to man for the following general reasons:

1. They are used as human food.
2. Their hides are a source of special kinds of leather.
3. They destroy other undesirable animals.

On the other hand, a smaller number of species are undesirable, usually because of one or both of the following reasons:

1. They are venomous.
2. They destroy useful animals.

Structures of reptiles. The reptile group includes the turtles, crocodiles, alligators, lizards, and snakes. They are vertebrates, and represent a type of development intermediate between that of the amphibian and that of the bird. Most reptiles have three-chambered hearts, but some crocodiles and alligators have four-chambered hearts. They are lung-breathers for the most part, and have well-developed digestive, nervous, and reproductive systems. Many of them lay eggs, but some species bear the young.

All of the reptiles are distinguishable from the amphibians because reptiles have external skeletons of plates and scales; amphibians do not. These external skeletons of the reptiles are of course the source of "tortoise shell," "lizard-skin" shoes, "alligator-skin" bags, and other personal accessories and novelties.

In the following paragraphs a few of the more important members of the reptile group will be mentioned with special reference to their usefulness to man, or in the cases of some species, with reference to their control, or the extent to which they should be considered a menace.

Turtles. Since various species of turtles are to be found in practically all parts of the United States, they are familiar objects to most people. They are characterized by having protective "shells" on their dorsal and ventral surfaces. These "shells" are composed of bony plates which are joined together. Likewise, turtles are interesting because as adults instead of teeth they have horny beaks.

All turtles lay eggs. Some species are marine; among them is the largest type, the leathery turtle, which attains a weight of one thousand pounds. Other species are found in fresh water and also on the land.

Turtles as food. The green turtle is a large, marine species, found in the warmer seas. Individuals weigh as much as five hundred pounds. These turtles and their eggs are of considerable value as human food. The rather small diamondback terrapin is another of the more famous members of the turtle group. It is used to make the celebrated terrapin soup. This species was formerly common along the South Atlantic Coast of the United States. It has been hunted for the market so persistently that it is now greatly reduced in numbers. Raising this species in captivity has been attempted with some success.

The snapping turtles and soft-shelled turtles of our inland waters are also used to some extent as human food. This use, however, is not extensive. These two types prey upon such desirable animals as certain fishes and frogs. The damage done may more than offset any benefits derived from using these turtles as food.

Tortoise shell. Tortoise shell was formerly prized for making combs and ornaments of various kinds. It is obtained from the hawksbill turtle, a marine species. This turtle has a dorsal covering composed of thirteen overlapping plates. The plates are melted down to form the tortoise shell of commerce.

Do turtles bite? Much has been said about the biting powers of certain turtles, especially the snapping turtle. It is true that some of them are capable of seriously injuring a human hand or finger. Even after the head has been severed from the body reflex action may cause the jaws to function for some little time. The writer has seen cases where it was necessary to cut the jaw muscles of the snapping turtles in order to release fingers that the turtles had seized in their mouths. Such cases are likely to occur when inexperienced fishermen attempt to remove hooks from the mouths of these animals.

Crocodiles. Some species of crocodiles are regarded as being a menace to human life. The Nile River and other African streams are famous for their crocodiles. Crocodiles are also found in Asia, Central America, South America, the West Indies, and even Florida. They usually live in swamps or along the banks of rivers and lagoons.

Crocodiles lie in the water near the shore, with only their nostrils and eyes showing above the surface, and seize unwary animals — even human beings in the cases of some species of crocodiles. The African crocodile and the salt-water crocodile of the Orient are well known for their attacks upon human beings. The black caiman of South America is also considered to be dangerous.

Crocodiles include the largest living representatives of the reptile group. The black caiman of South America, for instance, attains a length of twenty feet. Two species, the Indian gavial and the Madagascar crocodile, attain lengths of thirty feet. Of course, the regal python (a species of snake) compares favorably in so far as length is concerned. Like alligators, crocodiles have four short, stout legs; long, powerful tails; and tough hides covered with scales and plates.

In many respects crocodiles represent a higher type of develop-

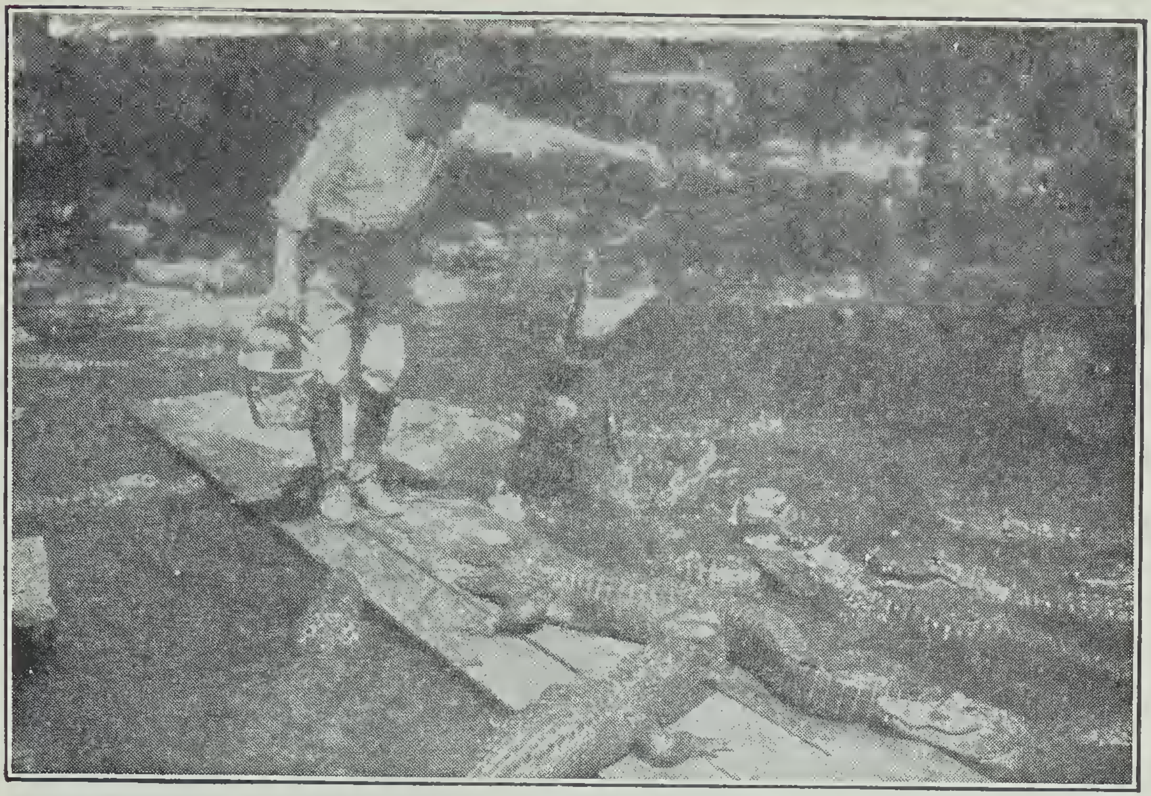


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FIGURE 240. Alligators in captivity.

ment than do the other reptiles. Their brains are not large, but they have four-chambered hearts and a sort of diaphragm dividing the body cavity.

A curious example for your notes on ecology is the relationship between the African crocodile and a species of small Egyptian bird. The historian Herodotus said that this bird cleaned the teeth of the crocodile. The fact is that the bird feeds upon leeches which infest the crocodile's mouth.

Alligators. The American alligator was formerly common in the southern states. It reaches a length of about sixteen feet. Nearly all of the larger specimens, however, have been killed or captured. Growth, apparently, is relatively slow. Alligators are typically swamp dwellers. The females lay twelve to forty eggs in a nest that is covered with dirt or vegetation. Both the eggs and the flesh of the alligator have been used as human food to some extent.

Alligator hides are by far the most important contribution of these animals to commerce. The hides have been used in manufacturing a wide variety of leather goods. Unfortunately, a great many alligators have been killed for no other purpose than so-called "sport." This is not desirable, because the alligators destroy various rodents which in turn are destructive to farmers' crops, and also because the practice reduces the available supply of alligator hides.

Venomous lizards. Although lizards occur in temperate zones, they are most common in the tropical and semitropical regions. Two North American types are said to be venomous. They are the gila monster and the beaded lizard. The gila monster is found in the southwestern part of the United States; the beaded lizard is found in Mexico and Central America.

Useful lizards. Except for these two venomous types, North American lizards are beneficial because they are insect eaters. Furthermore, some of the tropical iguanas (lizards) attain a length of several feet and are commonly used as human food. Their eggs also are eaten.

Horned "toad." Three of the most interesting, although not

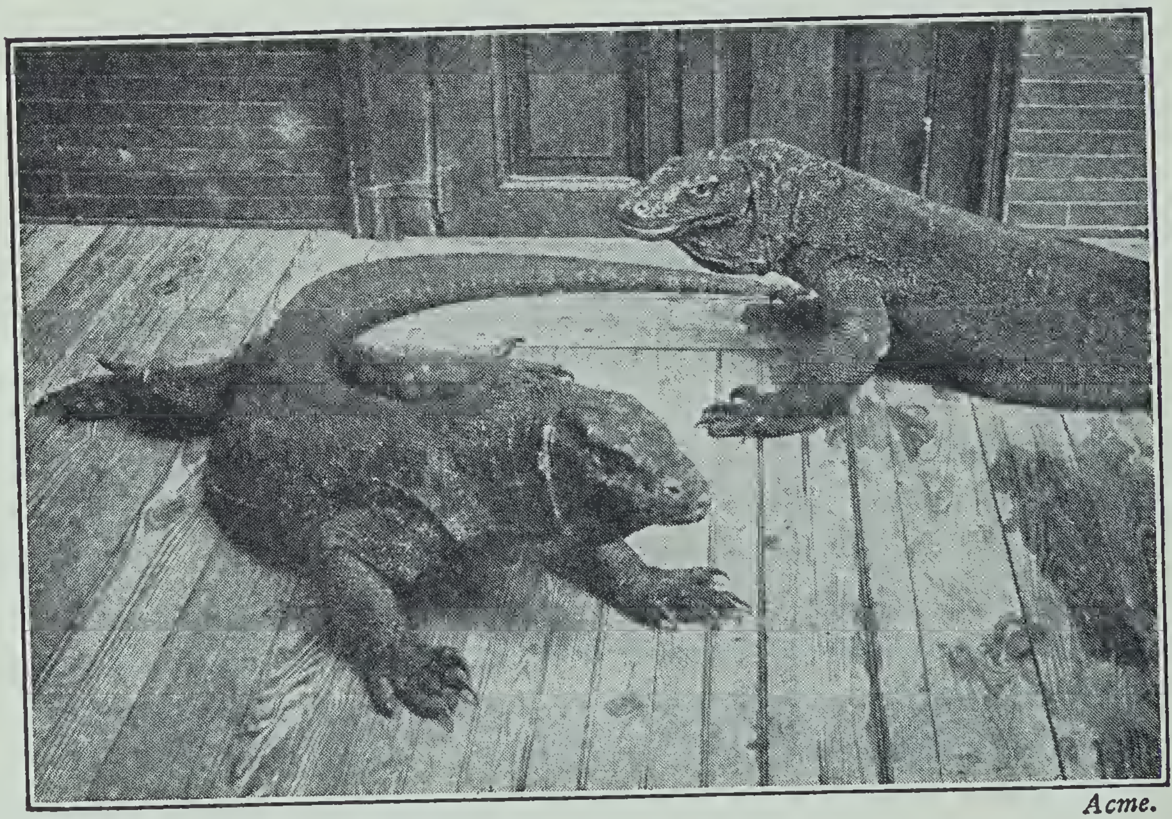

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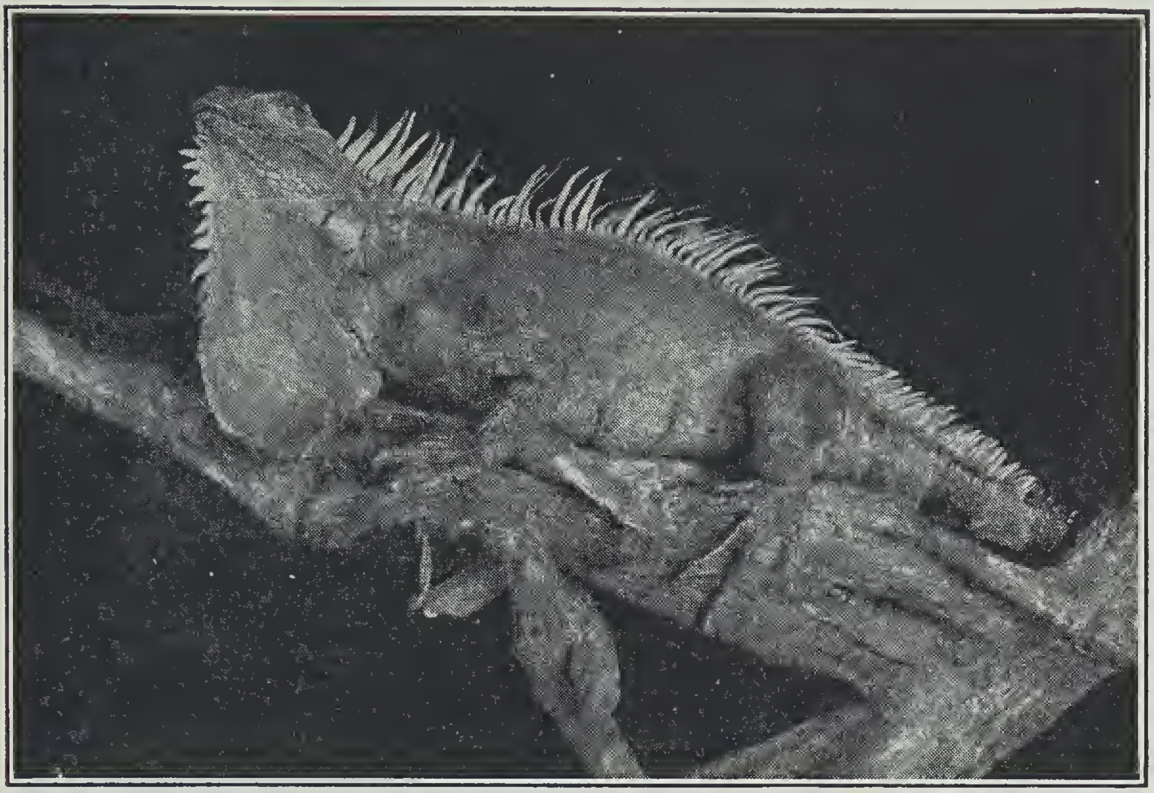
FIGURE 241. Giant lizards from the Dutch East Indies.



By Ewing Galloway, New York.

FIGURE 242. A large lizard (iguana) from the Central American region. Such animals are commonly used as food by the natives.

especially important, members of the lizard group are the "horned toad" (Phrynosoma), the so-called "chameleon" (Anolis), and the "glass snake" (Ophisaurus).

The "horned toad," found in the Southwest, is not a toad, but a short-bodied lizard. The so-called "chameleons" are not true chameleons, but live up to their name by having remarkable ability to change color.

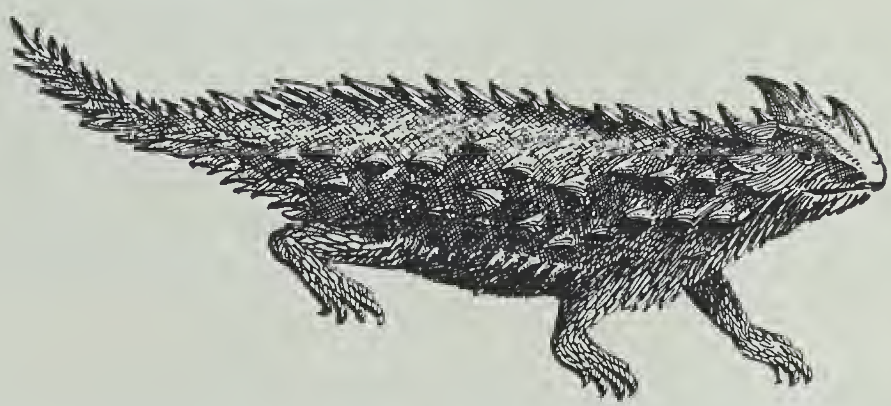


FIGURE 243. A horned "toad." This animal is in reality a member of the reptile group.

"Glass snake." The "glass snake" is not a snake, and of course is not "glass." It is called "glass" or "jointed" because, according to legend, it breaks into pieces when struck and the pieces are supposed to come together again. Most of this is untrue. The fact is that its tail breaks off rather easily when struck or seized by an enemy. Meanwhile the lizard attempts to escape, leaving its tail behind it. This animal does have some of the appearance of a snake, but is really a lizard, for it can shut its eyes and has depressions for ears, neither of which characteristics are typical of snakes.

Snakes. When we examine snakes without fear or prejudice we find that they are among the most beautiful and graceful of animals. Their skins have been used by uncivilized tribes for a long period of time. Only recently, however, they attained popularity among civilized peoples in the form of women's footwear, handbags, belts, and other leather goods.

Snakes are characterized by the absence of eyelids, and of limbs in the majority of species. Some species bear their young (viviparous), other species lay eggs (oviparous). Snakes shed or "molt" their external skeletons (commonly called skins), at regular intervals. They do not appear to have ears, although their slender, forked tongues may be sensitive to the vibrations of sound.

Do snakes bite? Snakes have short, sharp teeth that are so located in the jaws as to point backward. The teeth are not suited for chewing, and consequently the animals that are eaten by snakes are swallowed entire. The lower jaws of snakes are loosely joined to the upper jaws and this permits wider opening of the mouth cavity in the process of swallowing. Some of the smaller snakes swallow small birds, mice, toads, frogs, and rats. The largest known snake, the regal python (Python reticulatus) of Burma, can swallow much larger animals. The regal python attains a length of about thirty feet. Some of these larger snakes swallow such animals as deer, goats, and pigs.

Some species of snakes do seize their victims with their teeth, and so may be said to "bite" them. Most of our venomous North American snakes *strike* when attacking an enemy. The incisions in this case are caused by two of the upper teeth which are known as "fangs." These fangs may be moved so as to protrude almost straight forward when the snake strikes. The venom comes to the hollow fangs from two poison glands located in the sides of the head and neck region.

Garter snakes. Among the nonvenomous species of North American snakes are several species of garter snakes. These snakes are relatively small in size and are usually marked with three longitudinal stripes of orange or yellow. All of them bear their young, the females producing from ten to seventy-five at a birth. This relatively rapid rate of reproduction has been a factor in enabling garter snakes to survive in rather thickly settled parts of the country.

Garter snakes eat earthworms, frogs, toads, fishes, and perhaps a few insects, among other things. With the exception of insects, most of the animals eaten probably are useful to man. This

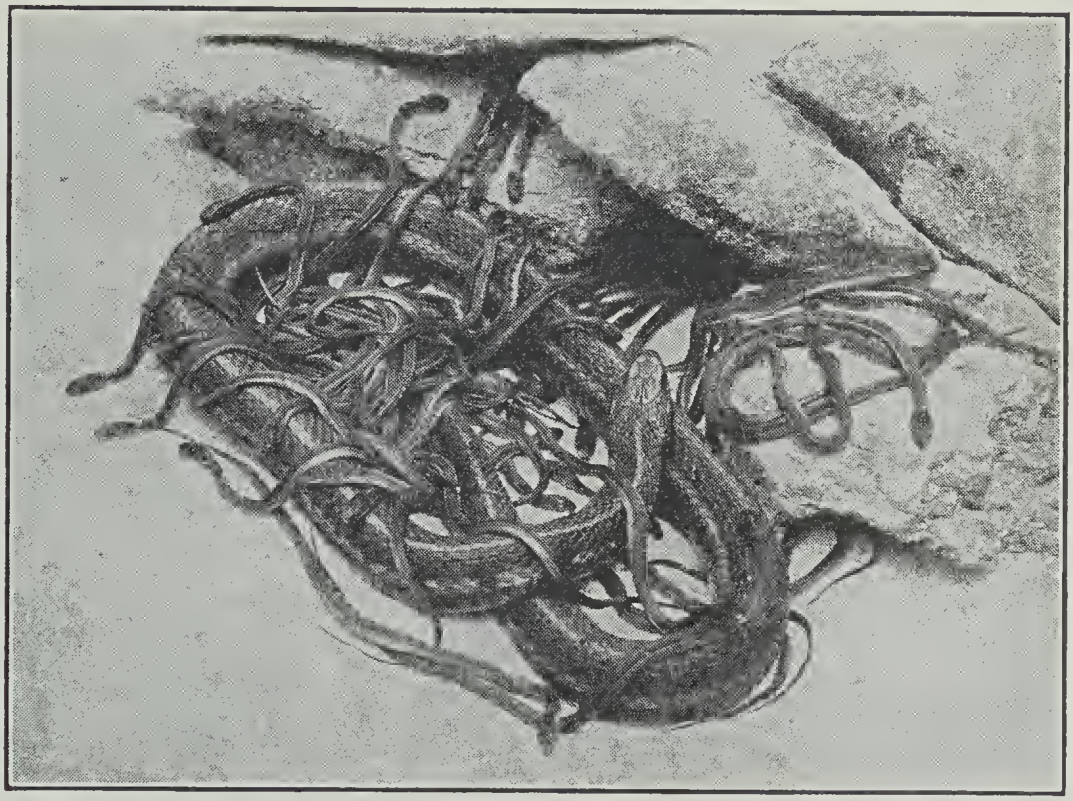
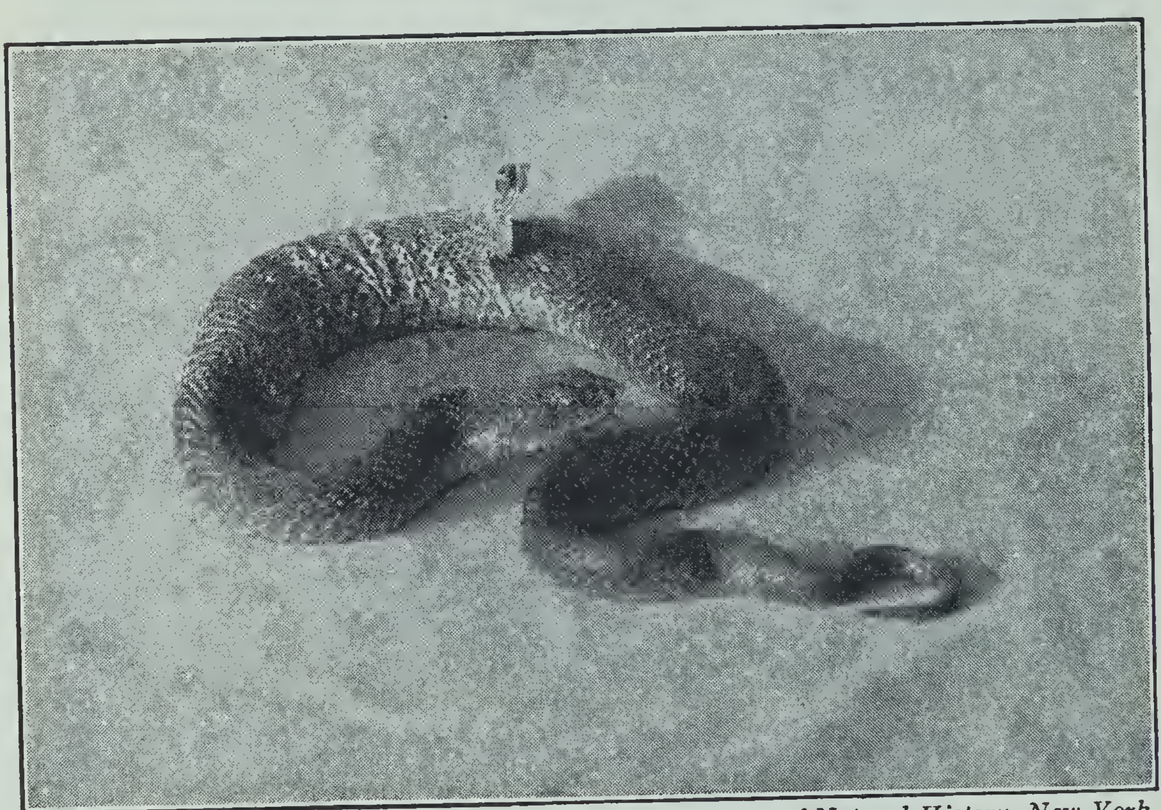


FIGURE 244. A female garter snake and newly born young. Do all snakes bear their young? (From *Reptiles of the World*, by Raymond L. Ditmars. Doubleday, Doran & Company. Courtesy of the author and the publishers.)

suggests that garter snakes are somewhat injurious, although when young they probably eat insects and other small animals for the most part.

Water snakes. Several species of water snakes belong to the genus Natrix. These are not to be confused with the venomous water moccasin, which belongs to a different family. The water snakes are nonvenomous species which habitually are found in or about the water. Like garter snakes, they are viviparous, and the females produce as many as forty young at a birth. Water snakes probably are undesirable species because they eat fishes, toads, frogs, and tadpoles. They do eat some insects and small mammals, but any benefit resulting from the destruction of insects is probably more than balanced by the harm done in the destruction of frogs, toads, and food fishes.

The writer formerly kept a "live-box" in the shallow water of a river. This "live-box" was a crate in which living fish could be kept for some time. On several occasions when the "live-box" was pulled out of the water, it was found to contain



American Museum of Natural History, New York.

FIGURE 245. A hog-nosed snake in the process of shedding its skin.

a water snake. The latter had been attempting to capture one of the fish. In fact, one large water snake was observed to capture a fish and make off with it through the open top of the "live-box."

Hog-nosed snakes. The hog-nosed snakes probably are so called because they have upturned snouts. They also are called "puff adders," "spreading adders," and "blowing vipers," because when alarmed they sometimes will inhale a quantity of air and then slowly exhale with a hissing sound. They are sometimes said to be venomous, but this is not true.

The hog-nosed snake may feign death, or "play 'possum," when it is threatened by danger. In doing this the snake lies quietly upon its back. The amusing thing is that if the supposedly dead snake is turned over, it will sometimes turn back of its own accord and then continue to feign death.

The economic status of hog-nosed snakes is in doubt. They eat some injurious rodents and insects. On the other hand, they eat the useful frogs and toads.

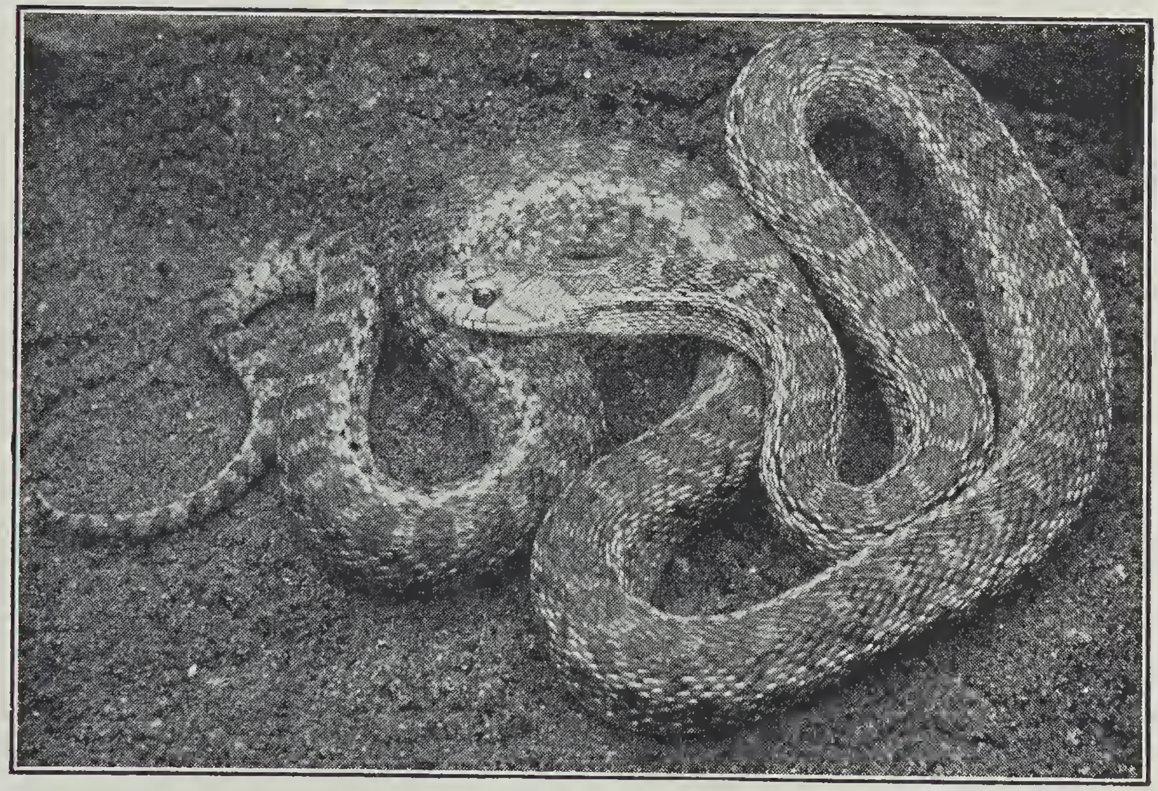


FIGURE 246. A bull snake. (From *Reptiles of the World*, by Raymond L. Ditmars. Doubleday, Doran & Company. Courtesy of the author and the publishers.)

Bull snakes. Among the most useful North American snakes are the bull snakes. Three species are found in the United States. They are comparatively thick-bodied and often reach a length of six feet. They are not venomous. Bull snakes eat many harmful rodents, such as rats, mice, and gophers. Some farmers have learned to protect them in so far as this is possible. Unfortunately they are often killed by automobiles while in the act of crossing highways, and also are killed by mowing machines operating in the fields. Bull snakes are oviparous.

King snakes. The king snakes are represented by seven species in the United States. They are nonvenomous. King snakes are beneficial because they eat injurious rodents and because they kill and eat venomous snakes. It seems that the common king snake (Ophibolus getulus) is immune to the venom of the venomous North American snakes. The milk snake is a member of the king-snake group that is beneficial because it destroys many rats and mice.

Among the other beneficial and nonvenomous North American snakes are the black snake, the blue racer, and the pilot black snake. Some of these species probably are more valuable to man than others, but all of them are eaters of rats, mice, and other undesirable rodents.

Venomous snakes. Venomous snakes are species that have glands which secrete a poisonous substance known as venom. This venom, as we have noted, is transferred to a victim through the medium of enlarged, hollow teeth known as fangs.

Coral snakes. The coral snakes (Micrurus) are venomous. They are relatively small snakes, attaining a length of about eighteen inches. Two species occur in the United States. They are marked by bands of scarlet and black separated by narrow bands of yellow. Coral snakes are of interest because they are not closely related to the rest of the venomous North American snakes, but are more closely related to the Oriental cobras.

Pit vipers. The better-known venomous snakes of North America belong to the pit-viper group. This group includes the rattlesnakes (at least a dozen species), the water moccasin, and the copperhead. All of these species bear rather characteristic markings by which they may be distinguished from other North American species. These markings are:

1. The presence of a "pit" between the eye and the nostril.
2. Pupil of eye elliptical rather than round.
3. Wedge-shaped head.

Pit vipers are able to move their fangs, which are attached to the anterior end of the upper jaw, until they point forward. These snakes are typical of the species that strike rather than bite their victims. The resulting wound consists of two holes close together. When not in use the fangs of the pit vipers are folded against the roof of the mouth.

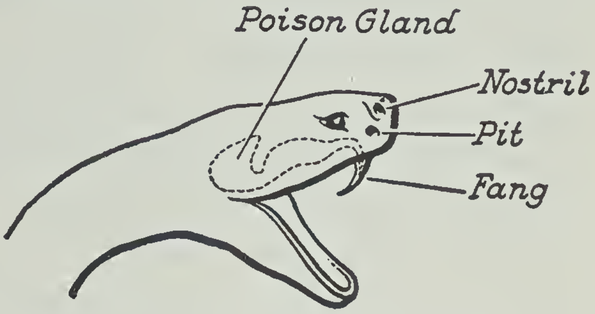


FIGURE 247. Diagram illustrating the relationship of a venom gland and a fang in a rattlesnake.

Rattlesnakes. Among the better-known species of rattlesnakes are the timber rattlesnake, the diamondback rattlesnake,

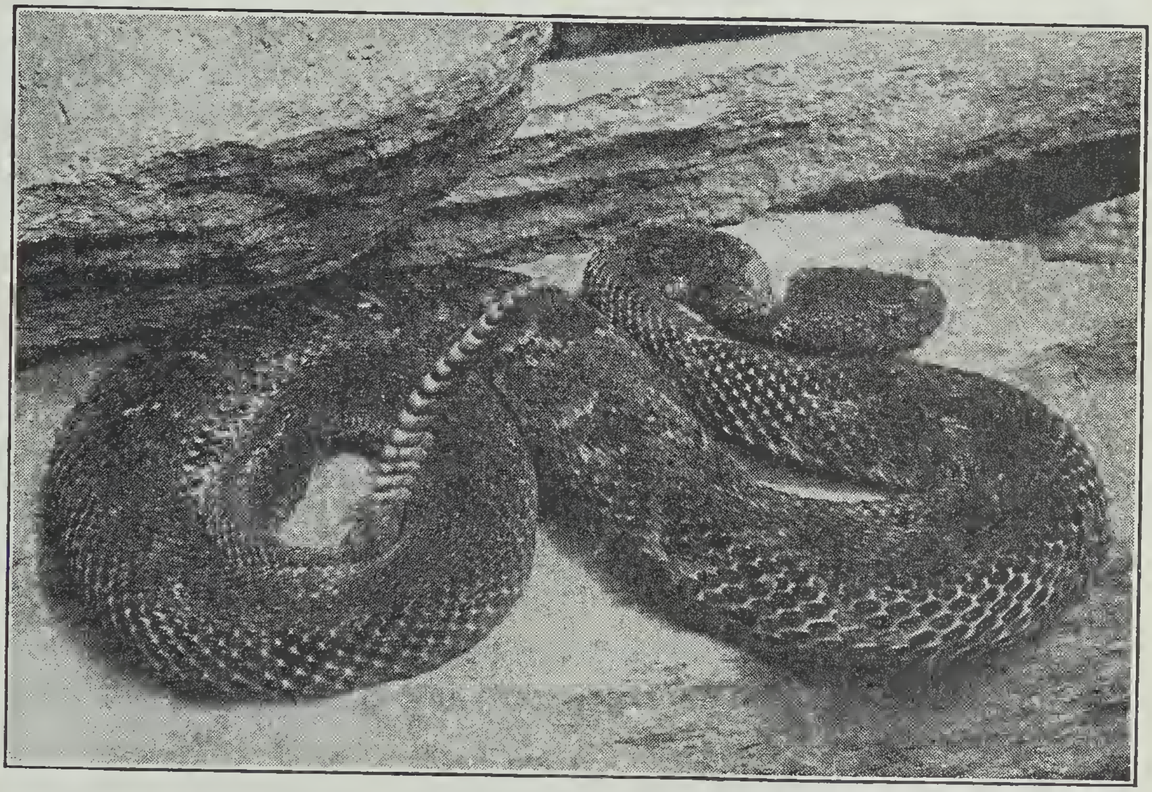


FIGURE 248. A timber rattlesnake. (From *Reptiles of the World*, by Raymond L. Ditmars. Doubleday, Doran & Company. Courtesy of the author and the publishers.)

and the massasauga. All species of rattlesnakes develop the characteristic "rattles." The expression "sixteen rattles and a button" is supposed to indicate a nineteen-year-old rattlesnake, on the assumption that each rattle represents a year and the button at the end of the group requires three years to form. The fact is that one rattle is formed each time a snake molts or sheds its external skeleton. Since the number of times a snake molts within a year is variable, and since the rattles often are broken off, the number of rattles cannot be depended on as a criterion of the snake's age. The various species of rattlesnakes are found over a wide area in North America.

It is certain that rattlesnakes are more widespread in distribution and therefore a more general menace than any other species of venomous snake found in the United States. The writer has the skins of four rattlesnakes killed in various parts of the country: one in the Yosemite, one in the Yellowstone, one in the Adirondacks, and one in Pennsylvania. They represent different varieties of rattlesnakes. Incidentally, all four of them attempted to escape by taking refuge in piles of rocks or in the brush. Only one of them coiled to strike, and this individual was deliberate about coiling and made no effort to attack the observer. This snake measured over four feet in length, had nine rattles besides the button, and contained in its digestive canal four mice in various stages of digestion. Perhaps even rattlesnakes have some desirable qualities, but they are too dangerous to be welcome neighbors.

Copperhead. The copperhead is native to the eastern part of the United States. Although it has been more or less eliminated in some regions, it is still found in timbered or mountainous areas. It is one of the smaller pit vipers and ordinarily is less than four feet in length.

Water moccasin. The water moccasin is a large and dangerous pit viper. It is typically found in swamps or near streams and ponds. A southern species, it ranges as far north as Missouri and Illinois. It is sometimes called the "cottonmouth" because the inside of its mouth has a whitish appearance.

Treatment of snake bites. Being bitten by a venomous snake often can be prevented by wearing high-topped leather boots or leather puttees when in a snake country. When an individual *is* bitten by a venomous snake, the services of a physician should be sought at once. Meanwhile, first aid may be given by placing a tourniquet between the wound and the heart. In the absence of more suitable materials, such a tourniquet may be constructed out of a large handkerchief tied around the limb between the wound and the heart. A stick is thrust beneath the cloth and twisted until the circulation is reduced. The area around the wound will swell, and the tourniquet should be moved from time to time to keep ahead of the swelling. The tourniquet should not shut off the circulation entirely for any length of time. To do so may result in a case of gangrene.

The wound may be cut open with a sharp, sterile knife, and a moderate amount of bleeding encouraged. In fact, it is desirable to remove as much venom as may be possible by using a suction bulb as supplied in snake-bite kits. Some authorities believe this to be a very important measure, and certainly no one should venture into a snake-infested region without such equipment. The victim should be kept quiet, and a physician should be brought to the patient, if this is at all possible.

Potassium permanganate has been used to offset the effects of snake venom. Sometimes the crystals are placed in the wound after it has been cut open with a knife. Or sometimes a solution of potassium permanganate in water is used to wash out the wound or is injected into the surrounding tissues with the aid of a hypodermic needle. Objection has been raised to the use of potassium permanganate on the ground that it injures the tissues when used in solution strong enough to have any real value. At the present time, antivenom serum (antivenin) is available for use. It is injected hypodermically. It is advisable that people who venture into regions where there is danger of being bitten by any member of the pit-viper tribe should go supplied with antivenom serum.

The deadliness of the bite of a venomous snake depends upon a number of factors. The smaller individuals have less venom and are therefore not so dangerous as their larger relatives. The position of the wound is important; the situation is more hopeful if the wound is in a spot where there are few large veins. In such a case the venom will not enter the general circulation as rapidly as it otherwise might. It is probable that in many cases not enough venom is injected to prove fatal, provided that the victim does not "die of fright." Prompt and efficient first aid, and treatment by a physician if the latter is at all possible, are very important. There was formerly a belief to the effect that drinking quantities of intoxicating liquor would aid the injured person. This is of doubtful value — as a matter of fact a large amount of alcohol in the system would probably be a severe handicap to recovery.

Myths concerning snakes. There are many foolish superstitions about snakes. Milk snakes do not steal milk from cows or from the farmer's cellar. The forked tongue of the snake is in itself quite harmless to man. It is not a "stinger"; it is probably an organ of sensation. The "hoop snake" is a myth. This snake is supposed to stick its tail in its mouth, form a rigid loop, and roll down hills or mountain slopes. Other amazing powers have been attributed to the "hoop snake." The so-called "pilot" black snake does not accompany the rattlesnake or warn the latter of danger. "Snake feeders" are ordinary dragonflies; they do not "feed" or "doctor" snakes. Snakes are not slimy; their bodies normally are dry. There is no evidence that snakes "charm" their victims; any such apparent effect doubtless is the result of fear.

Summary. In conclusion, we have found that a number of fishes, amphibians, and reptiles are of economic importance to man. Many species of fish are used as food throughout the inhabited world. Some species of amphibians, such as frogs, and reptiles, such as iguanas, turtles, or alligators, are also used as human food upon occasion. We obtain shagreen and gelatin from sharks, and manufacture articles of commerce from the hides of alligators and the skins of snakes. Some of the venomous snakes and the crocodiles might be regarded as natural enemies of man. Other species are of importance in that they destroy injurious animals, as the toad destroys undesirable insects. There are species which destroy useful animals, and therefore are considered undesirable.

SUGGESTED ACTIVITIES

Scientific methods

A biologist does not destroy living plants or animals, except for the benefit of human life.

1. If a museum or zoological park is available, examine species of fishes, amphibians, and reptiles discussed in this chapter.
2. After consulting the reading references at the end of this chapter, prepare a report upon the importance of fish as food.
3. Report upon methods employed in an effort to conserve and replenish the supply of food and game fishes. (See references.)
4. What explanation can you offer for the fact that some species of salmon ascend fresh-water streams to spawn?
5. After consulting the reading references at the end of this chapter, prepare a report upon the economic importance of toads.
6. Prepare a table which lists the various species of snakes discussed in this chapter. In a second column indicate whether each species is venomous or nonvenomous. In a third column indicate the economic importance of each species.
7. If materials are available, examine a first-aid kit designed for use when an individual has been bitten by a venomous snake.
8. Self-testing exercise. Which response from column A is most appropriate for each of the statements in column B?

A	B
1. Flounders	*a.* a source of gelatin
2. Menhaden	*b.* a fresh-water fish
3. Sharks	*c.* both eyes on the same side of the head
4. Herring	
5. Carp	

A	B
1. Salamander	*a.* a source of tortoise shell
2. Horned toad	*b.* a lizard
3. Snapping turtle	*c.* an amphibian
4. Green turtle	
5. Hawksbill turtle	

A	B
1. Cobra	*a.* a pit viper
2. Copperhead	*b.* noted for ability to kill and eat venomous snakes
3. Bull snake	*c.* an important venomous type found in the Orient
4. Coral snake	
5. King snake	

SUMMARY OF PRINCIPLES

1. Some vertebrates are useful to man because they are used as food and because they provide various materials of commerce, or because they destroy injurious animals.
2. Some vertebrates are injurious because they destroy materials or organisms that are useful to man.
3. The herring, shad, codfish, mackerels, flounder, halibut, swordfish, and salmon are among the important marine food fishes.
4. Many of the fresh-water fishes are valuable as a source of food.
5. Frogs and toads are beneficial because they eat insect pests.
6. Some reptiles, such as tropical lizards and various species of turtles, are used as human food.
7. The skins of some reptiles, such as snakes and alligators, are used in making special kinds of leather.
8. Some of the reptiles, including a number of the snakes, are beneficial because they destroy undesirable insects and rodents.
9. Some species of snakes are undesirable because they are venomous.
10. Some reptiles are undesirable or of doubtful value because they destroy useful animals, such as frogs and toads.

GUIDE QUESTIONS

1. What kinds of animals are included in the vertebrate group?
2. What articles of commerce are obtained from the various vertebrates?
3. To what extent are sharks beneficial, and to what extent are they undesirable?
4. What are the important species of marine food fishes?
5. What results have followed the introduction of the carp in the United States?
6. Why are salamanders considered to be beneficial?
7. How can you distinguish between the amphibian and the reptile on the basis of external appearance?
8. What uses are made of alligator and snake skins?
9. What species of North American lizards are venomous?
10. What is meant by "venomous"?
11. Why are garter snakes and water snakes of doubtful value?
12. Which species of North American snakes are beneficial?
13. Which species of North American snakes are venomous?
14. What is a "pit viper"?

BOOKS TO READ

Ditmars, R. L. *Reptile Book.*
Fitzpatrick, F. L. *The Control of Organisms.*
Haggard, H. W. *The Science of Health and Disease.*
Hegner, R. W. *Parade of the Animal Kingdom.*
Hegner, R. W. *Practical Zoology.*
Metcalf, Z. P. *A Textbook of Economic Zoology.*
Noble, G. K. *Biology of the Amphibia.*
Reese, A. M. *Outlines of Economic Zoology.*

CHAPTER XXXVI

THE BIRDS

Problems:

1. In what ways do birds affect human welfare?
2. How may desirable species of birds be protected and conserved?

MOST BIRDS ARE BENEFICIAL

(As destroyers of weed seeds, insect pests, and rodent pests)

Foreword. Birds belong to the Class Aves. They are the only feathered vertebrates, and their closest relationship is with the reptiles. Modern birds generally develop beaks and have no teeth.[1] Most birds, but not all species, are aërial; that is, they are able to fly.

The ability to fly has enabled birds to pass back and forth across mountain ranges, rivers, deserts, and even oceans. Consequently, they have developed rather widespread geographical distribution. The travels of birds constitute one type of animal migration, which is discussed more fully in another chapter.

Migration has some relationship to the economic importance of birds. Certain kinds of birds band together in flocks during the migration season. If the birds in question are grain-eaters, large flocks may cause serious damage in harvest fields.

Importance of birds. Generally speaking, a species of bird may be beneficial for one or more of the following reasons:

1. Because it eats quantities of weed seeds.
2. Because it destroys insect pests.
3. Because it destroys rodent pests or other undesirable animals.

The great majority of the bird species belong either to the beneficial group or are approximately neutral in economic importance.

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[1] Except embryonic teeth as in a type of tern (sterna).

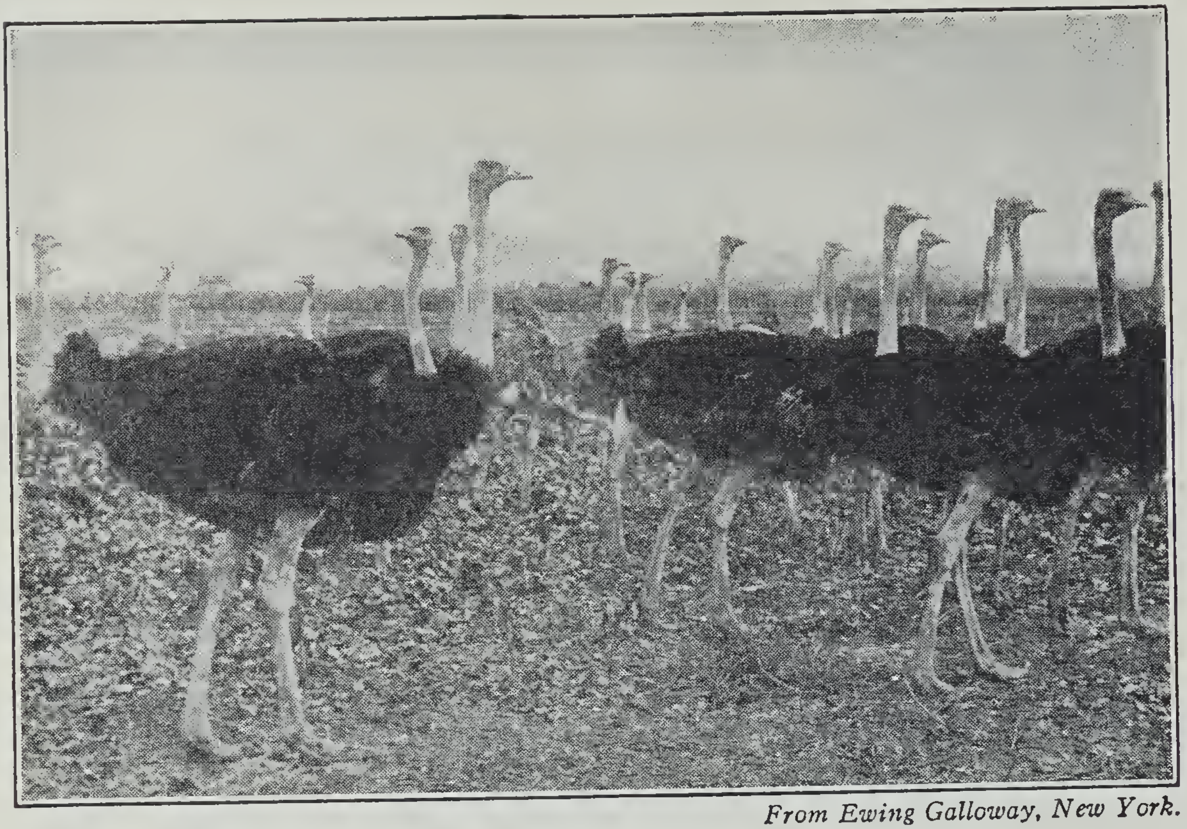
A few species of birds are injurious for one or more of the following reasons:

1. Because they eat quantities of cultivated grain.
2. Because they eat quantities of cultivated fruit.
3. Because they destroy garden crops.
4. Because they prey upon useful animals.

The ostrich. The largest living bird is the ostrich, which reaches a height of over eight feet. It is native to Africa and southern Asia, and has been at least partially domesticated. Ostrich farms have been established in South Africa, Australia, and the United States. The birds are raised for their plumes or feathers. Ostriches cannot fly, but are rapid runners. They normally are vegetarians or eaters of plant materials, but are noted for their ability to swallow pebbles and other hard objects. The belief that the ostrich will attempt to conceal itself from an enemy by sticking its head in the sand is untrue.

Ducks and geese. Ducks and geese belong to the same order of birds. They are aquatic or semiaquatic birds, usually found in or about water. Several species have been domesticated within comparatively recent times. Ducks have been hunted in the United States since the first days of settlement. To a considerable extent their nesting places in northern North America have been destroyed by the draining of lakes and swamps. These and other factors have resulted in a rather alarming decrease in numbers, especially in the cases of some species. Many ducks formerly nested in the northern part of the United States, but now it appears that there is a tendency to go farther north and to nest in Canada. Ducks and geese are protected to some extent by state and federal laws, but these laws do not necessarily conserve their nesting places.

Hawks. The hawks make up another large group of birds. They are, in most cases, beneficial or at least neutral, because the various species destroy many insect pests or rodent pests. However, a few species, including Cooper's hawk and the sharp-shinned hawk, are injurious because of their attacks upon poultry and wild birds. Unfortunately, there has been a lack of discrimination between the few injurious species on the one hand



From Ewing Galloway, New York.

FIGURE 249. A group of ostriches on an ostrich farm.

From Ewing Galloway, New York.

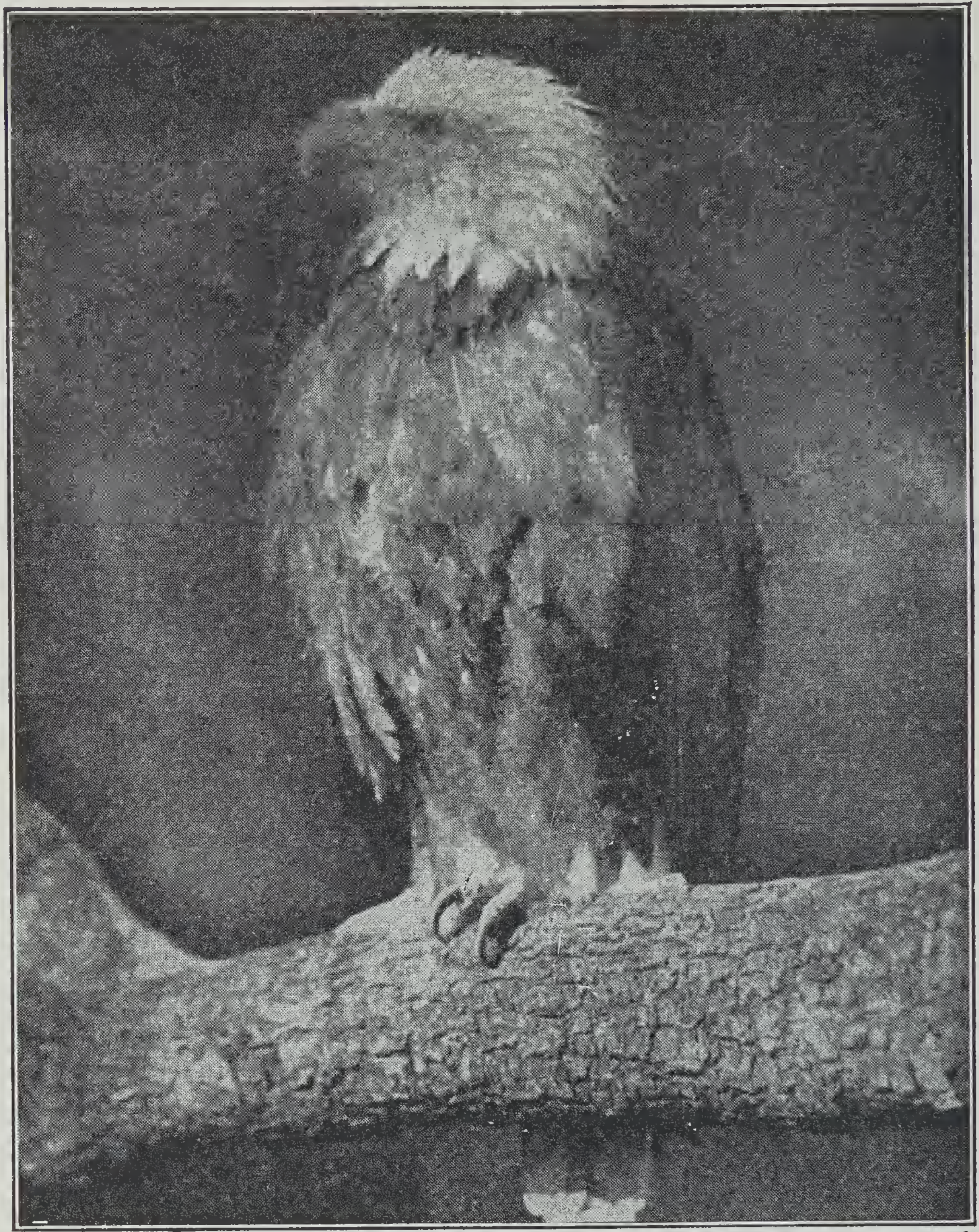
FIGURE 250. Ducks and geese resting and feeding in a marsh.

and the many neutral or beneficial species on the other hand. As a result, many useful hawks have been killed upon the assumption that they were the so-called "chicken hawks." Too many people have taken the attitude that all hawks should be killed, and as a result many of our most useful birds have been destroyed. At the present time most of the different species of hawks are protected by state and federal laws.

Among the more useful species are the broad-winged hawk, the rough-legged hawk, and the sparrow hawk. The broad-winged hawk eats a great many insects such as grasshoppers, beetles, caterpillars, and crickets. The rough-legged hawk destroys a great many mice, gophers, and other rodent pests. The sparrow hawk eats many mice, house sparrows, and grasshoppers. These three species occasionally might attack poultry or wild birds, but the injury done is far outweighed by their useful activities.

It is interesting to note that Cooper's hawk and the sharp-shinned hawk are among the smallest of hawks. One would hardly expect them to be successful in attacks upon grown chickens, but such is the case. The writer once observed such an attack upon a grown chicken by a sharp-shinned hawk. The chicken had strayed rather far from the poultry yard and was scratching about some old logs in a wooded field. The little hawk swooped down and alighted upon the chicken's back. A short struggle ensued, but the result was never in doubt; the chicken was no match for its aggressive enemy. The hawk centered its attack upon the chicken's head and soon dispatched its victim. Then it alighted on one of the logs and calmly awaited the end of the chicken's struggles, after which it proceeded to eat portions of its victim.

The chicken. One relatively important group of birds includes the chickens, pheasants, bobwhites, quail, and turkeys, among other species. The domesticated chicken is descended from the Indian jungle fowl. It represents a very old domestication, but the jungle fowl is still found in the wild state. The chicken has been carried to all parts of the world by man, and is the most important member of the poultry group. Many domesticated varieties have been developed through selective breeding.



From Ewing Galloway, New York.

FIGURE 251. An eagle — a type of bird closely related to the hawks. Note the formidable bill and claws.

The guinea fowl. The guinea fowl represents a much newer domestication. It is derived from an African bird that still exists in the wild state. In comparison with the chicken, the guinea fowl is wild, given to roaming, and is not so well adapted to life in confinement. This is the usual thing in cases of recent domestications.

The turkey. The domesticated turkey comes from a wild turkey of North America. It probably was first domesticated by the natives of Mexico, and represents another comparatively recent domestication. Various species of pheasants also are raised in confinement. Some of the important domestications of the future may come from these species.

The wild turkey and the prairie chicken have been hunted actively since the early days of settlement, with the result that they have all but disappeared from many parts of their former ranges. The numbers of ruffed grouse have been reduced markedly, and the same has been true of the bobwhite in parts of its range.

The ring-necked pheasant has been introduced into a number of localities in the United States, to offset the reduction in the numbers of native game birds. This pheasant is a hybrid produced by crossing the English pheasant and the Chinese ring-necked pheasant.

Gulls and terns. The gulls, terns, and shore birds comprise another rather extensive group. Many of the species included probably are about neutral as to economic importance. But some of them are valuable destroyers of insects. The black tern is frequently found in the interior of the country in the neighborhood of prairie lakes and ponds. It includes a good many insects in its diet. The same is true of a number of other terns and gulls. They have been valuable in the control of grasshoppers in particular. The Wilson's snipe (jacksnipe) and the American woodcock are members of the shore-bird group. They have been prized highly as objects of sport. As a result they have become greatly reduced in numbers, especially the woodcock.

Pigeons and doves. The pigeon and dove group includes the mourning dove. The passenger pigeon, which formerly was such a common bird in North America, was a member of this group. This passenger pigeon was hunted relentlessly for the market. The market hunting, and perhaps other factors, resulted in a very rapid reduction in the numbers of passenger pigeons, with the re-

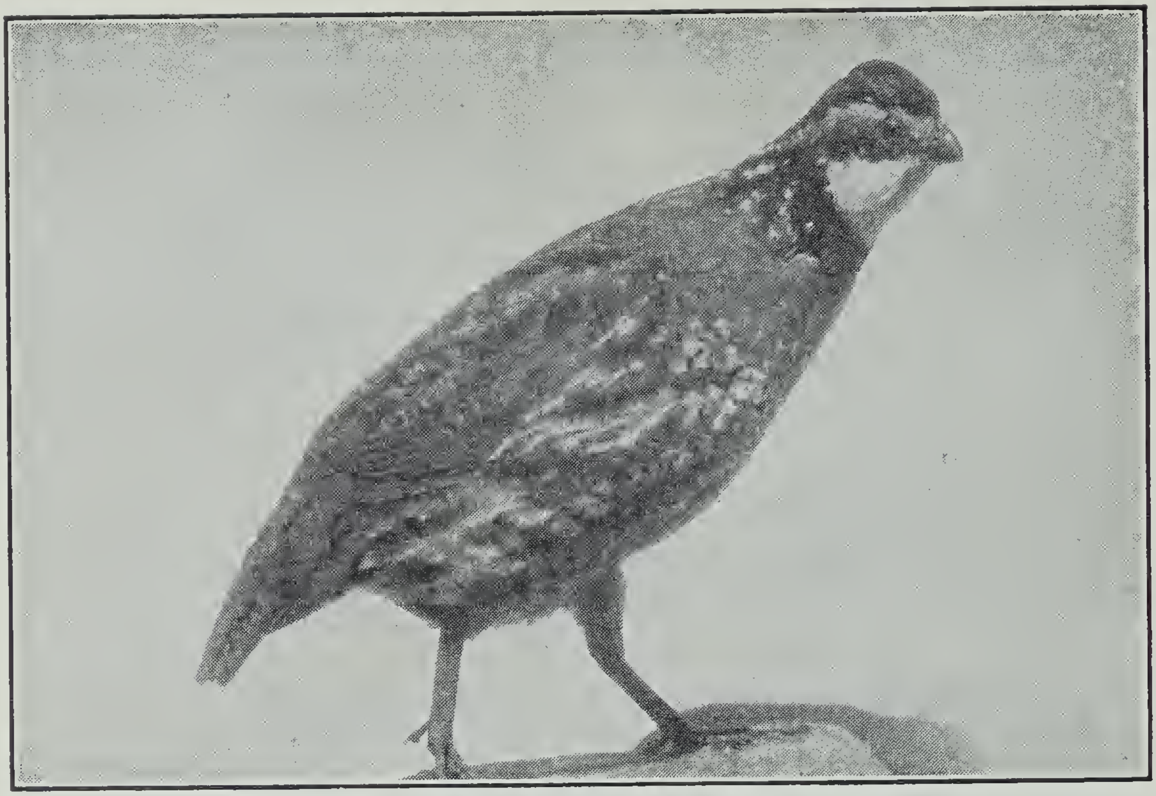


FIGURE 252. The bobwhite.

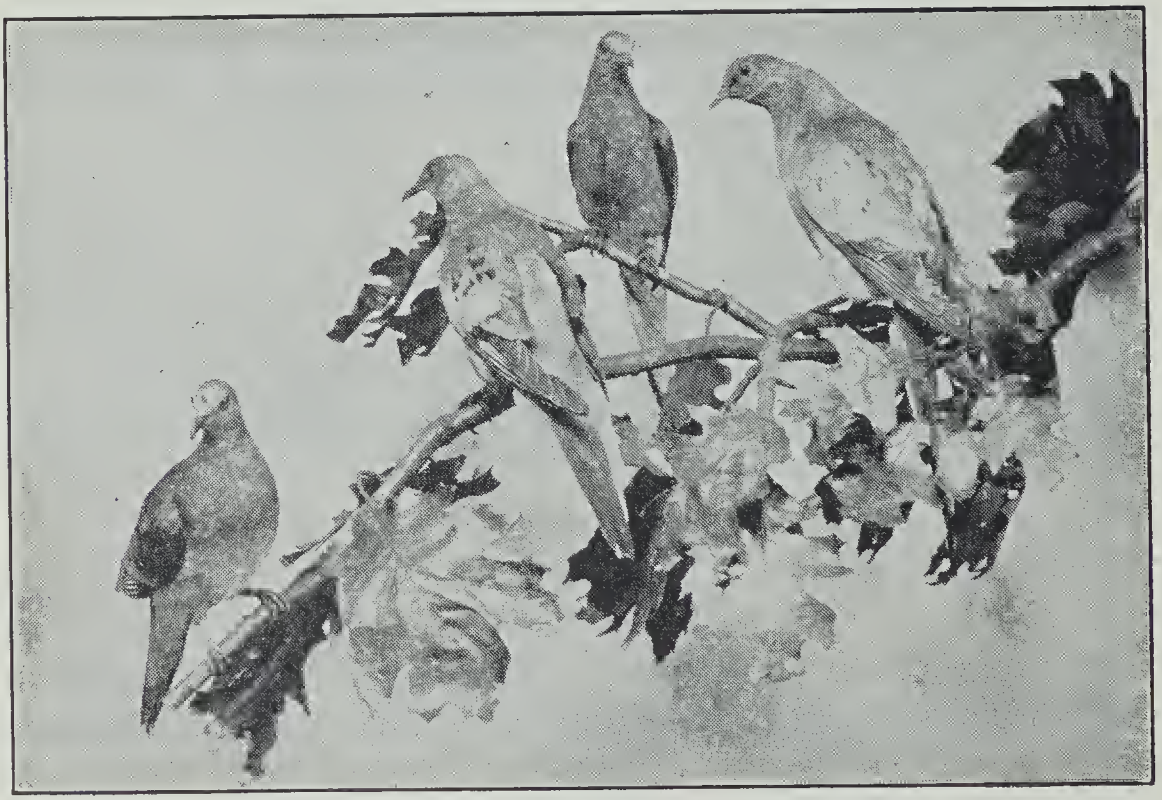


FIGURE 253. The extinct passenger pigeon.

sult that the species is considered to be extinct at the present time. At least there have been no authentic records of this bird for a number of years. The domestic pigeon has been derived from the blue rock pigeon of Asia. Like the chicken, it represents a very old domestication and many varieties have been developed.

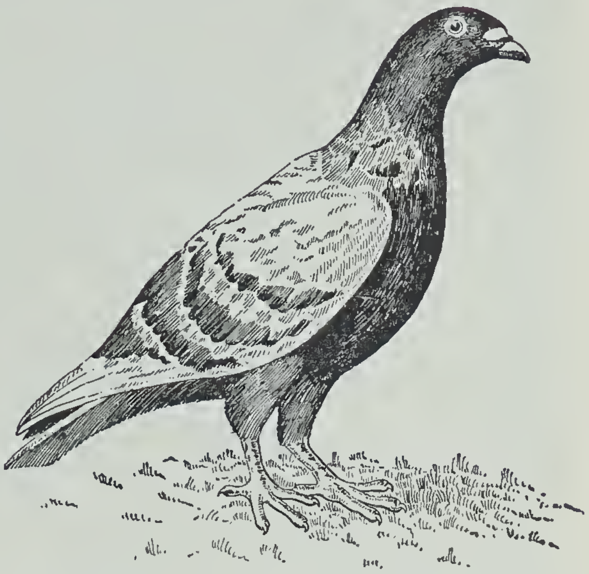


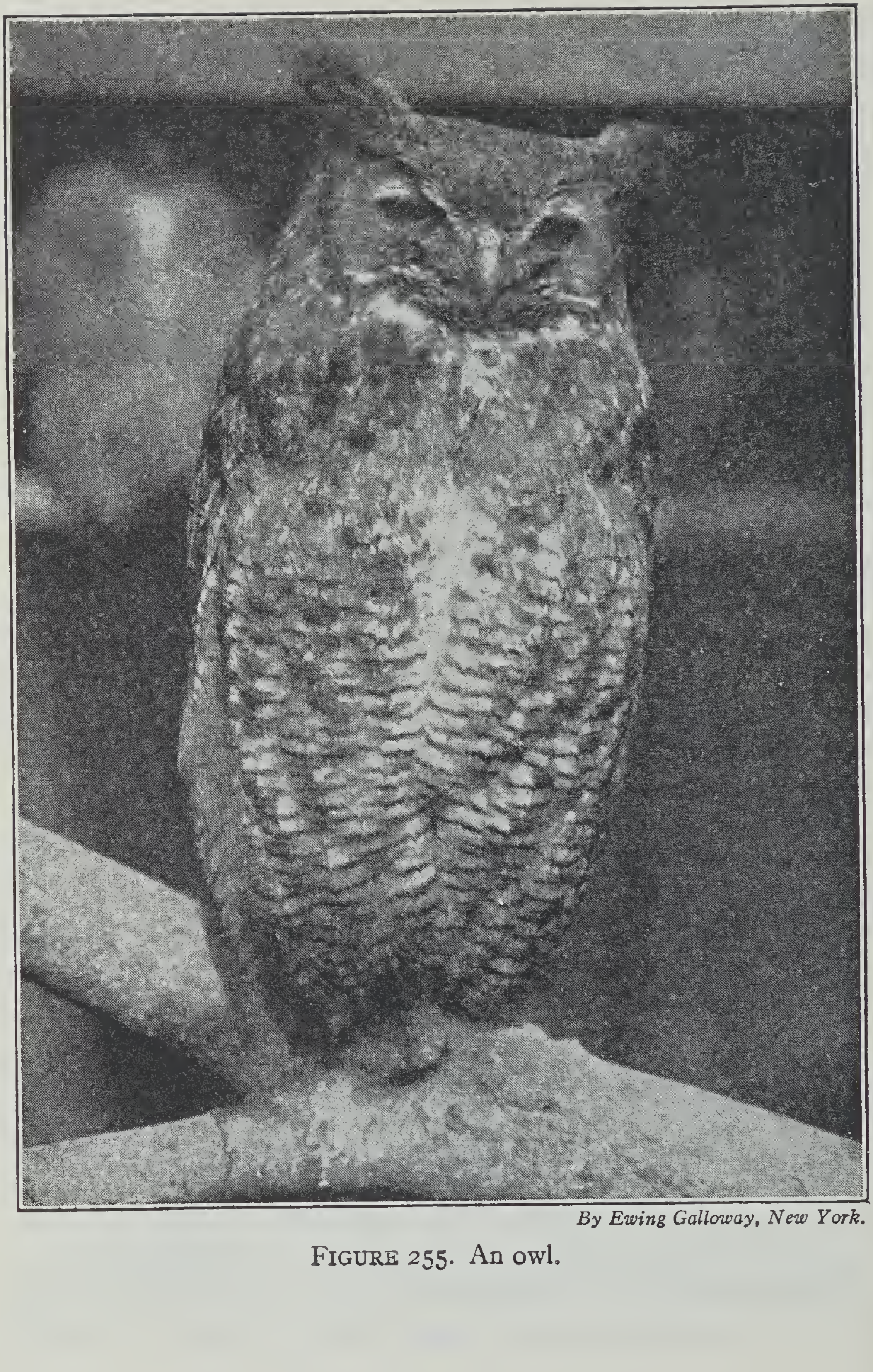
FIGURE 254. A domesticated pigeon.

The owls. Generally speaking, the owls make up another useful group of birds. The great horned owl is one species which is likely to be a nuisance in the more thickly settled parts of the country. But even this species is desirable in sparsely settled regions, where it acts as a check upon the increase of prairie dogs, gophers, and rabbits. Among the owls that are distinctly beneficial are the screech owl and the barn owl. The screech owl eats a great many mice and house sparrows. The barn owl eats mice, house sparrows, and rats.

Nighthawks. The nighthawk and the whippoorwill are examples of birds that eat almost nothing but insects. These insects are caught on the wing. Included among the insects eaten are such pests as mosquitoes, flies, and gnats. Both of these birds normally are woodland species. The destruction of forests has resulted in a reduction of their numbers in some localities. Recently, the writer observed a pair of nighthawks nesting on the flat roof of one of the larger buildings in a city. It will be observed that the term "nighthawk" is somewhat misleading, since these birds are not members of the hawk group.

Swifts. The chimney swifts are also valuable destroyers of such insects as mosquitoes, gnats, and flies. They have developed the interesting habit of nesting in unused chimneys.

Woodpeckers. Woodpeckers are, for the most part, beneficial, because they destroy many insects which in turn are enemies



By Ewing Galloway, New York.

FIGURE 255. An owl.

of forest trees. Woodpeckers have chisel-like bills which enable them to penetrate the bark and wood of trees and capture the wood-boring larvæ of these insects. The flicker eats many ants and grubs, in addition to other insects. The downy woodpecker and the redheaded woodpecker are among the better-known species belonging to this group.

Perching birds. The perching birds are supposed to be the most modern of birds. Most of them are small in size, and the group includes the so-called "songbirds." Because of their small size, they are not used extensively as human food, at least not in the United States. As a matter of fact, most of them are protected by state and federal laws. However, many of the species involved have become reduced in numbers because of the destruction of nesting sites and the removal of trees and bushes which bear wild fruits. A few species eat a limited amount of cultivated fruit. This is probably due to the fact that wild fruits have become scarce in many localities.

A large number of the perching birds are insect-eaters for the most part. This group would include many of the flycatchers, swallows, wrens, vireos, warblers, orioles, and thrushes. Swallows, for instance, feed almost entirely upon insects.

Another large group of perching birds are predominantly seed-eaters. Included in this group are many of the native sparrows. The seeds eaten are largely weed seeds.

House sparrow. A sharp distinction must be made between the numerous species of native sparrows and the introduced house sparrow or English sparrow. While the native species of sparrows keep to the fields and subsist largely upon weed seeds and insects, the house sparrow seems to prefer to live near the habitations of man, and is given to eating grain. The house sparrow was introduced into the United States in 1851–52 and has spread into most parts of North America. Aside from its grain-eating habits, it is undesirable because it competes with native birds, and builds its nests in or about buildings.

Starling. Another introduced species, the starling, is likely to prove fully as undesirable as the house sparrow. The starling was brought to the United States in 1890. Its economic status has not yet been decided, but it is extending its range westward rather rapidly. It has been reported from west of the Mississippi River several times within the last few years.

Crows, jays, and blackbirds. A number of the perching birds are more or less omnivorous; that is, they have a mixed diet. To this group the jay, the crow, and the blackbirds might be assigned. Some of these eat grain in sufficient quantities to make it a matter of economic importance. On the other hand, they also eat considerable numbers of undesirable insects. It seems probable that the injury done to farmers' crops is more than offset, in many cases, by the beneficial results arising from the destruction of undesirable insects. In other cases, the birds probably are about neutral in economic importance.

IT IS DESIRABLE TO PROTECT AND CONSERVE MOST SPECIES OF BIRDS

The value of birds. In conclusion, it may be said that the great majority of bird species are beneficial from the standpoint of man. Obviously, these species should receive protection and be conserved in every possible manner. Nevertheless, we find that many species have become reduced in numbers, some of them to the point of extermination. Game laws have been devised for the protection of birds, and these have had beneficial effects.[1] However, there are a number of other factors, not covered by existing laws, which contribute to the elimination of bird life. Some of these are included in the following list:

1. The destruction of forests removes the nesting places of many woodland species.
2. The draining of lakes and marshes has destroyed many of the nesting places of shore birds, ducks, and other semi-aquatic species.

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[1] The Migratory Bird Treaty Act (United States and Great Britain) makes it unlawful to kill, capture, sell, or transport migratory birds, their nests, or eggs in the United States and Canada. Certain "open seasons" may be provided for in the case of game birds. The Lacey Act provides that the Secretary of Agriculture may regulate importation of birds to the United States. It also makes it unlawful to ship birds from a state where it is not legal to kill them. In addition the states have their own laws which supplement treaties and federal laws.

3. Native trees and bushes that bear fruits have been destroyed in many localities. These fruits formed a source of food supply for many birds. Some of these species probably have changed or will change their food habits to meet the new conditions. Other species probably will be less fortunate.
4. Some species of birds continue to live in regions that have become centers of human habitation. In such cases they are menaced by a number of enemies, especially by cats. Few people realize how many birds are killed in the course of a summer by a cat. This is particularly true in the case of stray cats which are forced to find their food wherever they can.

Reforestation. Speaking generally, bird conservation cannot be limited merely to restriction of hunting by establishing the so-called "closed seasons" during which certain of the game birds are protected by law. Reforestation of waste lands undoubtedly would be an important factor in conserving our native birds. This reforestation is desirable, not only because it is likely to have a desirable effect upon the native bird population, but for purely commercial reasons. In reforestation projects, native fruit-bearing shrubs and trees should be provided for the special benefit of the birds. Setting aside parks and other wooded areas as bird sanctuaries also is very desirable. Birds appear to respond readily to protection, and tend to congregate in places where they receive it.

Birdhouses. Some species of birds can be encouraged to nest in yards and orchards, if "birdhouses" are provided for their use. Birdhouses can be constructed out of boxes or even empty tin cans. Their openings should only be large enough to admit the species of bird for which they are designed.

Winter feeding. Feeding birds during the winter, and especially during periods when the ground is covered by snow, is recommended. At such times some species of native birds which find their food upon the ground are handicapped greatly by the presence of the snow. If other sources of food are not available, they may not have sufficient energy to withstand the cold temperatures, and may die. Food may be provided for them by placing small grain on the ground out-of-doors. A piece of suet fastened to a limb of a tree will attract some species. The birds soon form regular habits of coming daily to such feeding places. It is not an uncommon thing in rural districts for the bobwhites (sometimes called quail) and the introduced pheasants to invade the farmers' chicken yards during cold, snowy weather. They do this in order to obtain some of the food that has been provided for the domesticated birds.

Summary. We may conclude our study of the birds by again emphasizing the fact that most species are useful to man, either directly or indirectly. Some species have been domesticated, others destroy weed seeds or insect pests. Only a few species eat cultivated grains or fruits to any great extent, or attack poultry and other wild birds. The reduction of the numbers of some species of birds is a matter for concern, and calls for the institution of conservation measures.

SUGGESTED ACTIVITIES

Scientific methods

A biologist studies the relationships of living things to each other, and especially to man.

1. Prepare a bird list for your community, indicating species which are residents, those that are winter visitors, and species seen only during the migration season.
2. After consulting the reading references at the end of this chapter, prepare a report upon the food habits of hawks and owls.
3. Describe, with the aid of drawings, the adaptations of bills and feet of ten species of birds. Classify them as perching birds, wading birds, swimmers, predaceous birds, etc. Mention the chief food or foods of each species.
4. Prepare a table of species discussed in this chapter. In three columns indicate: (*a*) name of species, (*b*) food habits, and (*c*) whether the species is beneficial or injurious.
5. Study the habits of five or more birds for several weeks. Record the actual behavior and modes of life you have observed in each case.
6. After consulting the reading references at the end of this chapter, prepare a report upon the subject "Why most species of birds should be protected."

SUMMARY OF PRINCIPLES

1. Many birds are of direct or indirect use to man because of one or more of the following factors:
    a. They are used as food.
    b. They destroy insect pests.
    c. They eat weed seeds.
    d. They eat undesirable mammals.
2. The harm done by a few species of birds consists of eating grains or fruits, and of preying upon small animals.
3. Most species of birds should be protected and encouraged by man.
4. Various means for protection of birds have been used, among which are:
    a. Work of the Biological Survey, and education by means of government bulletins.
    b. Protective federal and state laws.
    c. Closed seasons for game birds.
    d. Creation of bird sanctuaries and forest reserves.
    e. Providing nesting places.
    f. Feeding birds during the winter months.
5. Cats are among the birds' most active enemies.

GUIDE QUESTIONS

1. Name three birds which are seed-eaters and three which eat insects for the most part.
2. Name ten birds with which you are familiar. Give a distinguishing characteristic of each, and discuss their food habits.
3. Discuss four ways in which birds are useful to man.
4. What can individuals do to protect and encourage birds?
5. What factors tend to reduce the numbers of birds?
6. Name three of the less desirable species of birds, and indicate the type of injury in each case.

BOOKS TO READ

Chapman, F. M. *Handbook of the Birds of Eastern North America.*
Fitzpatrick, F. L. *The Control of Organisms.*
Henderson, Junius. *The Practical Value of Birds.*
Mann, P., and Hastings, G. T. *Out of Doors.*
Palmer, E. L. *Domestic Birds.* Cornell Rural School Leaflet, vol. 20, no. 4.
Peterson, R. T. *A Field Guide to the Birds.*
Reese, A. M. *Outlines of Economic Zoology.*
Rowan, W. *The Riddle of Migration.*

CHAPTER XXXVII

THE MAMMALS

Problems:

1. How does the presence of man affect other animals?
2. What mammals are useful to man, and for what reasons?
3. What mammals are undesirable from the human standpoint? How may these species be controlled?

Foreword. Mammals are distinguished by the fact that they develop hair. They have four-chambered hearts and are warm-blooded. The group to which they belong is called the Class Mammalia.

MANY MAMMALS ARE BENEFICIAL; SOME ARE INJURIOUS

Domesticated mammals. Man has domesticated or partially domesticated a number of mammals which have proved to be useful. Such species must be able to live successfully under domestication. The cow, pig, horse, dog, goat, sheep, and the camels are among the forms that have been domesticated for a long time. To this list might be added many other species which are only partially domesticated at the present time. Some of these partial domestications of today may be among the successful domestications of the future.

Competitors. On the other side of the picture, a number of mammals are competitors or natural enemies of man. Most of these mammals have been reduced greatly in numbers with the advent of the modern firearm. The natural enemies among the mammals are not so much to be feared as are the legions of injurious insects, bacteria, and parasitic protozoa. The mammals that we classify as competitors eat food which man himself could eat or which might be eaten by man's domesticated animals.

Acme.

FIGURE 256. A herd of domesticated cattle. How does man utilize these animals?

Influence of man. Up to this point we have considered all animals solely from the standpoint of human benefit. It is interesting to note how the increase of human population, with the growing complexity of human civilization, has affected the other animals and especially the mammals. Some species undoubtedly have been benefited by man. Some of them have been preserved under domestication. Others have been carried into new environments, and in some cases these species have been benefited greatly by the changes in habitats.

On the other hand, the larger natural enemies and competitors of man are gradually being eliminated or at least greatly reduced in numbers. Certain species which have served as a natural supply of food or fur have suffered greatly.

The bison formerly was a common animal in western North America, but it was hunted almost to the point of extermination in the latter part of the nineteenth century. Only a few carefully guarded herds of bison remain today. The Canadian beaver formerly was common along the streams of northern North

America. But it was extensively exploited for its fur and now is not found, or is found only rarely, in many regions where formerly it was common. The remaining beavers survive largely because of legal protection. Much the same story might be told with regard to a number of mammals.

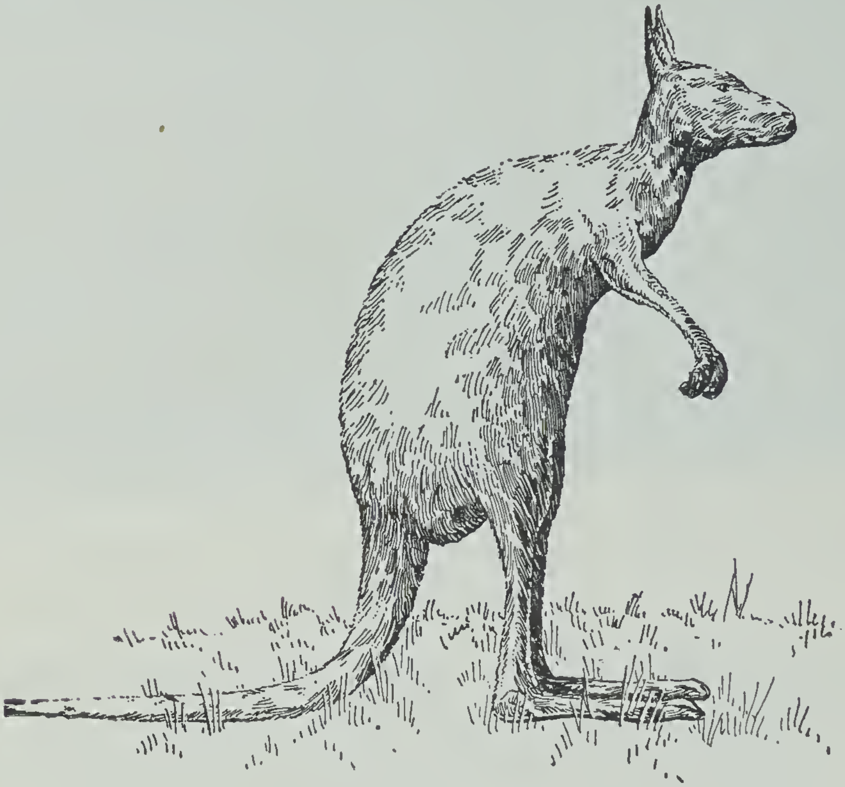
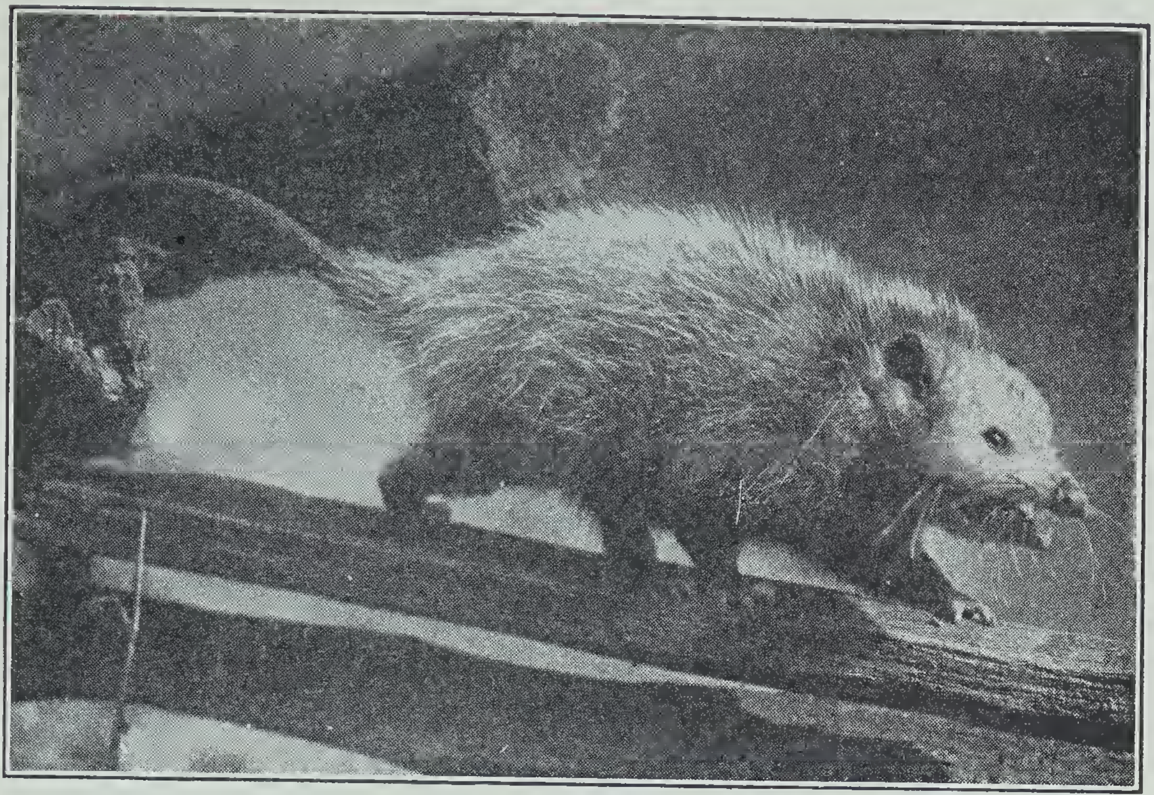


FIGURE 257. A kangaroo. Kangaroos are members of the marsupial group, found in the Australian region.

Kangaroos and opossums. One interesting group of mammals includes the kangaroos and opossums (marsupials). The kangaroos and the related wallabies are native to Australia. There are some sixty species varying from less than a foot to five feet in height. They are herbivorous and sometimes become a menace to crops if they are too numerous in any locality. On the other hand, their flesh is eaten and their hides are of value. The Virginia opossum is the familiar example of this group found in the United States. It has some value in that it is used as human food and its fur is used in making wearing apparel.

Many of our "animal stories" have little truth in them. But the common story to the effect that the opossum will feign death



J. C. Allen. From Ewing Galloway, New York.

FIGURE 258. An opossum.

has a basis in fact. The writer once observed a performance of this nature. An opossum had been captured and was placed on the ground quite uninjured. The opossum remained immovable with its eyes almost, but not quite, closed. It looked very much as if it might be dead. This "playing 'possum" continued as long as any men or dogs were in the vicinity, but as soon as the latter were out of sight, the opossum lost no time in making its escape.

Moles and shrews. Moles and shrews belong to another group of mammals. The common mole is well known for its habit of burrowing just beneath the surface of the soil. This burrowing is objectionable when it occurs on lawns. Otherwise, no particular damage is done except that the roots of garden plants are broken or severed in some cases. But the mole is not a root-eater. On the other hand, it eats worms, insects, and insect larvæ. Many of the cases wherein moles are supposed to have eaten plant roots are cases in which the damage has been done by pine mice. Pine mice burrow after the fashion of moles, or follow along mole burrows.

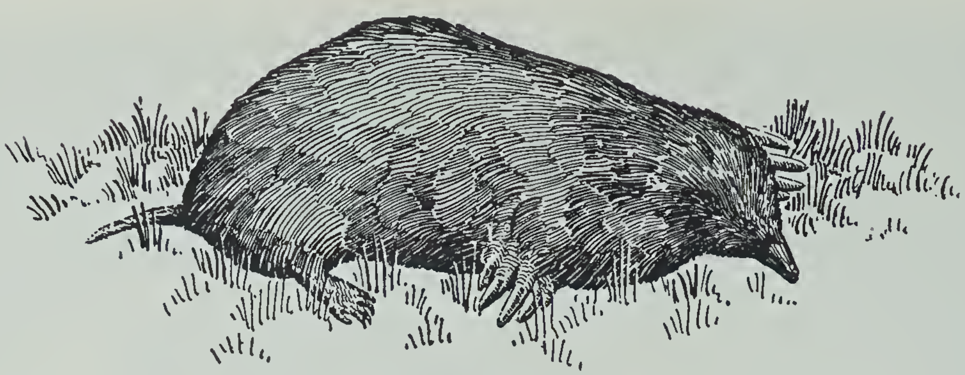


FIGURE 259. A mole.

Shrews are small mammals, found in the grasses of fields and meadows, and often mistaken for field mice by the casual observer. Closer examination will show that they are quite different from field mice; they have the type of teeth typically associated with eaters of insects. As a matter of fact, shrews do eat insects, and for that reason are beneficial.

Bats. About six hundred species of bats are found in various parts of the world, most commonly in the warmer regions. Some of them are very small, and other species are large enough to have a wing-spread of five feet. These larger species are called flying foxes. They are found in the Orient. Most bats are nocturnal animals, seeking their food during the hours of darkness and resting during the hours of daylight. They make their homes in deserted buildings, hollow trees, caves, and similar places.

Some of the bats found in the tropics become a nuisance if they are too numerous, because they are fruit-eaters. Some species gather together in flocks and invade cultivated areas where fruits are being raised. Some of the South American species are bloodsuckers. These species are known as "vampire" bats. They are known to attack cattle, horses, chickens, and other domesticated animals. Vampire bats bite their victims in order that they may be able to suck the blood which constitutes their food supply.

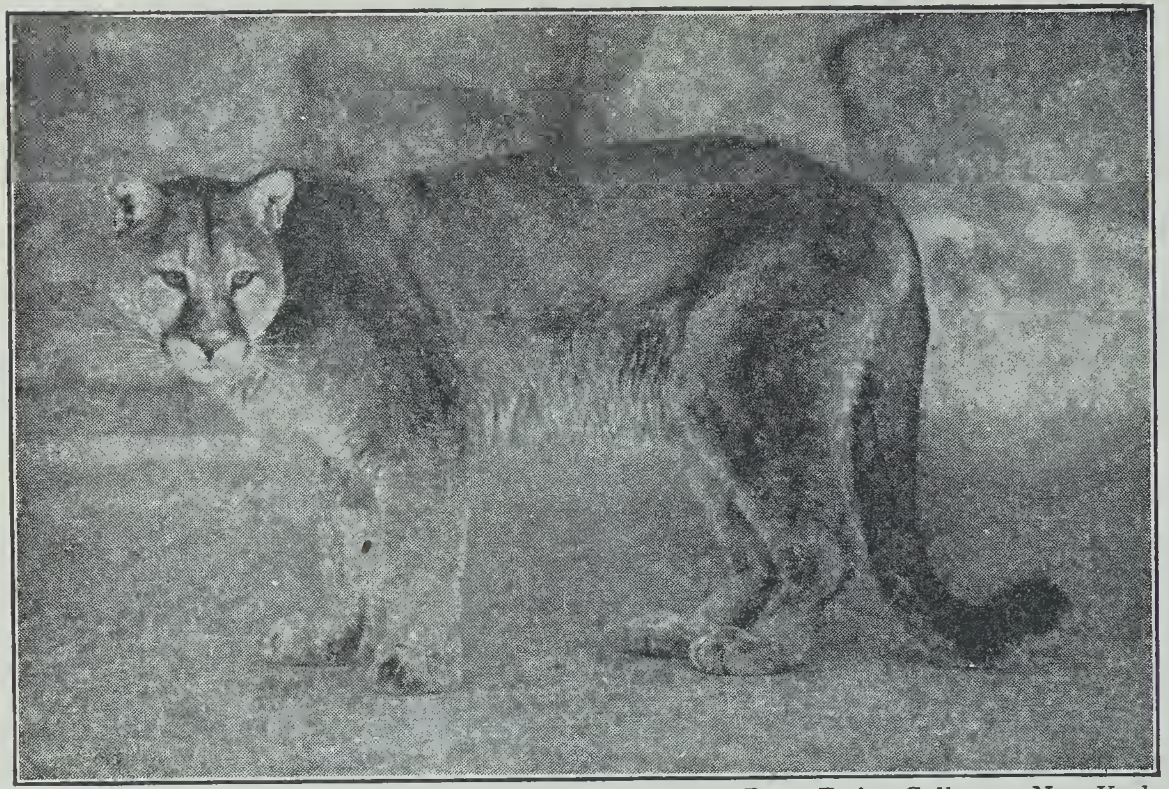
The bats found in North America, however, are not only harmless, but decidedly beneficial, because they destroy many mosquitoes, flies, gnats, and other undesirable insects. The common species are the little brown bat, the brown bat, and the red bat.

FIGURE 260. A fox. Foxes are members of the carnivore group.

These three species are comparatively small in size. The superstition to the effect that bats carry bedbugs (human) is untrue. So is the belief that bats will deliberately become entangled in women's hair. Such things *might* happen, but probably never do happen.

Carnivores. The carnivore group includes a number of typically predaceous, flesh-eating mammals. Carnivores have relatively long, pointed canine teeth. In fact all of their teeth are adapted to the process of eating flesh. The dog and the cat belong to this group. Both of these animals have been domesticated or partially domesticated for a long time, and a number of varieties have been developed by selective breeding. The dog has a mixed ancestry, involving wolves, foxes, and jackals.

Cat family. The tiger and the lion are among the most dangerous members of the carnivore group in so far as the physical safety of man is concerned. The former is still found commonly in parts of Asia, the latter in parts of Africa. Other members of the cat family are found in various parts of the world. The North American cats include the wildcat, the Canadian lynx, the moun-

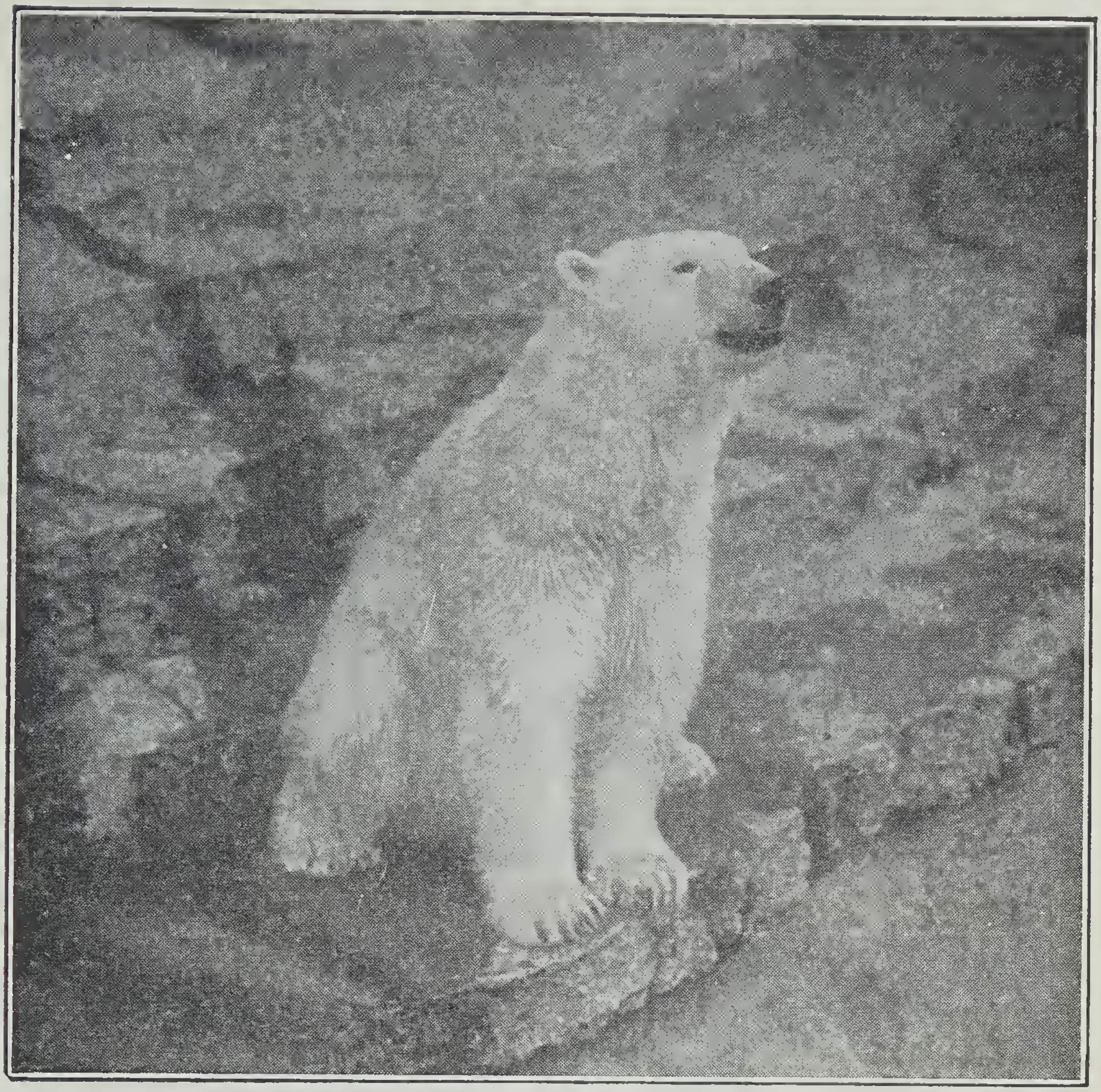


From Ewing Galloway, New York.

FIGURE 261. A cougar (mountain lion). This animal is a carnivore.

tain lion, and the jaguar. All of these species are destructive to birds and the smaller mammals. In addition, the mountain lion and the jaguar are quite capable of killing deer, calves, colts, and even grown cattle and horses. These animals survive only in unsettled parts of North America: the Canadian lynx in northern regions, the jaguar in Mexico, and the mountain lion in the Rocky Mountain region.

Wolves and coyotes. Wolves and coyotes — also carnivores — are found in various parts of North America. Wolves are typically timber animals, and they will attack larger mammals, including domesticated stock. For this reason they have been hunted to the point of extermination except in the more sparsely settled and inaccessible parts of the country. Coyotes are smaller than the typical timber wolves and are animals of the prairie and plain. They lack the aggressiveness of the wolves and ordinarily will not attack larger animals. However, they are quite capable of killing poultry, wild birds, and lambs. They have some value in that they destroy a good many jack rabbits and other undesirable rodents.

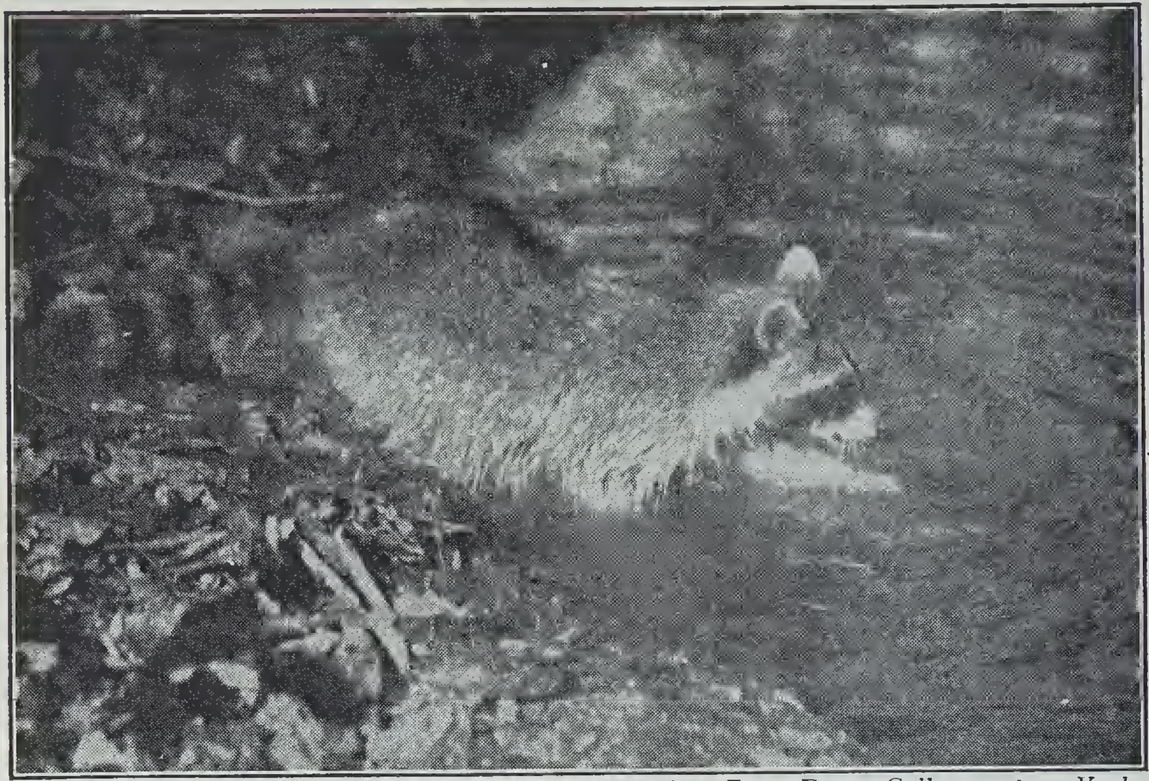


J. C. Allen. From Ewing Galloway, New York.

FIGURE 262. A polar bear.

Fur-bearers. Many of the North American carnivores are desirable because their fur is valuable. Included in this group are the red fox, the gray fox, the otter, the mink, the weasel, the raccoon, the skunk, and the fur seal. The bears have been utilized both for their flesh and their fur. Extensive trapping and hunting have greatly reduced the numbers of some of these species. The otter, for instance, has become quite rare, and a few years ago, the fur seal, whose home is off the Pacific Coast of North America, was threatened with extinction.

Probably because of the growing scarcity of fur-bearing animals, public interest has turned to the raising of skunks, minks,



Edwards. From Ewing Galloway, New York.

FIGURE 263. A raccoon at the edge of a stream. This is a carnivore which often catches and eats fish.

and foxes. The highly prized silver fox is a variety of the red fox. Silver-fox farming is carried on largely in Canada and some colder parts of the United States. The animals are not easy to raise, because they do not react well to confinement, and they often die of disease.

Rodents. The rodent group is one of the most successful groups of mammals, having a large number of species with widespread geographic distribution. Their success may be attributed to three general factors:

1. They produce relatively large numbers of young.
2. They tend to be omnivorous, and can subsist upon many different kinds of food.
3. Their small size enables them to find refuge in almost any locality — in the case of rats and mice, even in our largest cities.

Rodents are characterized by having gnawing teeth. Their incisor teeth are chisel-like in form and grow throughout life.

The flying squirrels, squirrels, ground squirrels, prairie dogs, woodchucks, beavers, rats, mice, gophers, porcupines, and rabbits belong to the rodent group.

Some of these species are beneficial, some are neutral, and some are decidedly injurious.

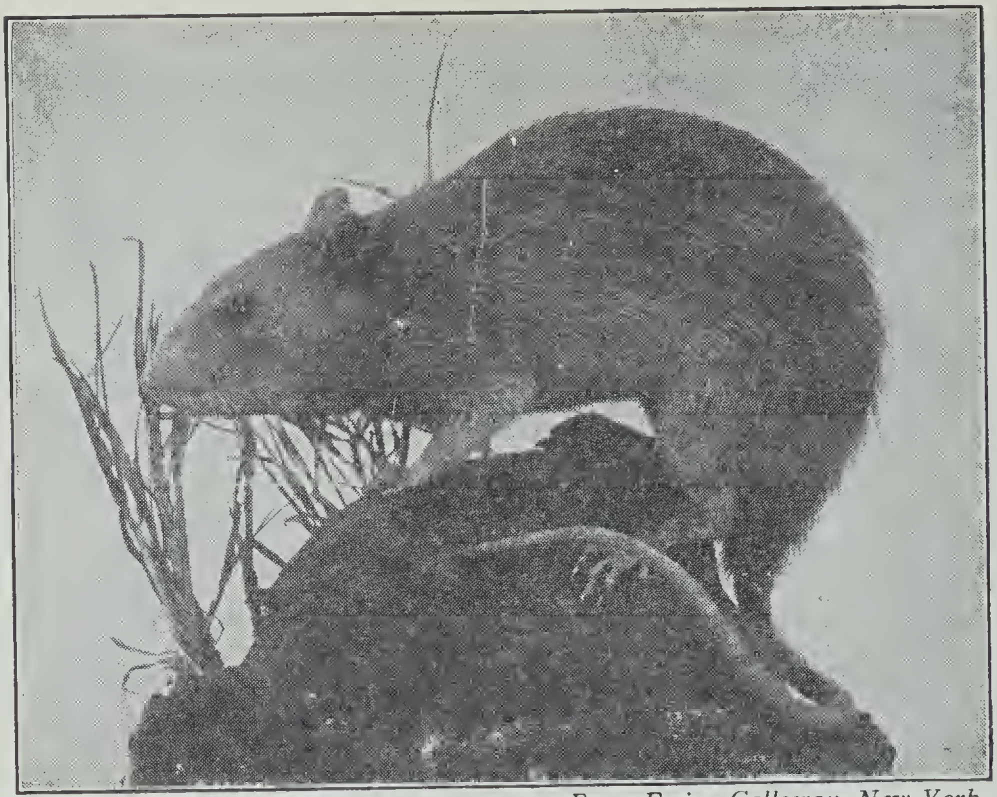
Squirrels are used for food, and their fur has some value. They have been known to destroy corn and other grain if present in large numbers, but ordinarily they are not numerous in regions where they are hunted. The chipmunks and flying squirrels are probably about neutral in their economic importance. Several species of ground squirrels are found in different parts of North America. Some of them are injurious because of attacks upon cultivated grain. Other species probably are at least neutral, and possibly beneficial if not too numerous. In the latter cases the ground squirrels are known to include a good many insects in their diet.

The California or digger ground squirrel is one of the less desirable types, because it eats a good deal of grain, and because it carries the fleas which are known to be responsible for the transmission of the bubonic plague.

House mouse. The most undesirable members of the rodent group undoubtedly are the mice and rats. The house mouse is a species that accidentally was carried to North America in the early days of settlement. It has established itself in almost all parts of the world where there are human habitations.

House mice reproduce rapidly. The females bear several litters of from four to nine young each year. They reproduce most rapidly when food is abundant. Australia had a mouse plague in 1917. At the time, vast stores of wheat had been accumulated and were awaiting shipment. The mice invaded the storage places, where plenty of food was to be had for the taking. Some idea of their numbers may be gained from the fact that eight tons of mice, representing about 500,000 individuals, were killed in one grain store in the course of four days.

House mice are injurious for a number of reasons. For one thing, they eat all sorts of food materials, and especially grain. During the harvest season they will desert the buildings, where



From Ewing Galloway, New York.

FIGURE 264. The house (or Norway) rat.

they might otherwise be living, and move out into the grain fields, where food is abundant. They also chew or gnaw all sorts of materials which they use in building their nests. They probably are directly or indirectly responsible for the transmission of some diseases.

House rat. It is thought that the house rat originally came from the Orient. At any rate, it was reported in England in 1729, and seems to have reached North America in 1775. It probably was carried to this country in shipments of goods. This species also reproduces very rapidly, the females bearing six to ten litters of young annually, with six to nineteen young to the litter. House rats are omnivorous, eating almost anything that is of organic origin. They chew up all sorts of materials, destroying much that they do not actually use. They have been known to chew the insulating materials on electric-light wires, to chew lead pipes, to burrow under foundations and cause them to collapse, and to mar or destroy all sorts of woodwork.

In addition, they carry the fleas that disseminate the deadly bubonic plague. They also carry the trichina worm, and no doubt are directly or indirectly concerned in the dissemination of other diseases. In fact, the presence of rats constitutes a very definite civic problem.

Habits of rats. During the winter, rats congregate in cities, towns, and about farm buildings. They find refuge under floors, in walls, in sewers, in piles of rubbish, or in stored materials. They ordinarily are nocturnal, but may be abroad in the daytime in out-of-the-way places. During the summer, and especially in the harvest season, some of the rats go out into the fields, where they remain until colder weather begins. The writer has found one or two house rats, several house mice, and several field mice under one large shock of corn. It is estimated that the annual damage produced by the house rat in the United States is about two hundred million dollars.

Control of rats and mice. It is harder to destroy the house rat than it is to destroy the house mouse. For one thing, rats are more clever than mice. Rats learn to avoid traps and other dangers. They even work together in groups, in a sort of community co-operation. They commonly migrate from places where food is scarce, or where there are many dangers, to places where food is obtained easily and where they are not persecuted. It is possible to reduce the numbers of rats and mice, however, by carrying out some or all of the following measures:

1. Rats and mice can be killed by fumigation. This is effective if the buildings can be sealed tightly while they are being fumigated. The poison gases used are dangerous to human life and should be used only by experts.
2. Poison baits may be used if they can be placed where no other animals will get them.
3. Construct buildings which are mouseproof and ratproof. Concrete floors, foundations, and walls are effective barriers. Even drains and sewers should be screened.
4. Make food inaccessible by storing it in secure places. Grain should be harvested promptly and stored in ratproof and mouseproof granaries.
5. Do not allow piles of rubbish to accumulate. Some city dumps provide ideal refuges for rats and mice.

6. Encourage natural enemies, such as most hawks and owls, and some of the snakes. Ferrets sometimes are used to drive rats out of holes.
7. Community co-operation is necessary. It is of little value to drive rats and mice out of one building if the surrounding buildings provide havens of refuge.

Native mice. Many native species of mice also are very undesirable because of their attacks upon garden and field crops. Meadow mice are good examples of this group. They live in shallow burrows or in the grasses and weeds of meadows and fields. They eat grain, seeds, leaves, stems, bark, bulbs, and roots, injuring many cultivated plants. Each mouse is said to consume from twenty-five to thirty-six pounds of vegetation every year.

Pocket gopher. The pocket gopher is another highly undesirable rodent. It is a burrowing species, and one that lives in communities. The burrows are very extensive, and if the gophers have lived in a field for a long time, they may cover a wide area. The dirt is brought to the surface to form the characteristic "gopher hills."

Gophers eat the roots of alfalfa, clover, and other plants. They do not hibernate, and as a result they store underground large supplies of roots for winter use. Crop plants are destroyed, the gopher hills are obstacles to cultivation of the soil, and the burrows are responsible for rapid erosion of the soil during rains.

Gophers are caught through the use of steel traps, but this process requires some skill on the part of the trapper. They may also be killed by gassing them or using poison baits. Again, this requires some technical knowledge.

Beaver. The Canadian beaver is a semiaquatic rodent, desirable because of its valuable fur. One of the incentives for exploration of western North America in the early days of settlement was the desire to find new areas in which beavers might be trapped. It was not long before the beaver was eliminated from many parts of its former range. Today it is found only where it is given protection, notably in some of the Rocky Mountain states. A few beavers exist in the Adirondacks and other parts of New York State.

Beavers are famous for their ability to construct dams and beaver houses from mud, sticks, and other materials. Some of their dams cause the flooding of large areas, such as a mountain valley. The water may cover roads, meadows, and timberlands. Any prolonged flooding of timberlands results in the death of many trees.

Muskrat. The muskrat is another semiaquatic rodent. Its ideal habitat is a pond bordered by fields of corn. A certain amount of the corn will be used as food, and the depredations may be rather serious if the muskrats are numerous. Muskrats build houses similar to those of the beaver. The floors of the houses are above the water level, but all entrances are under water. Muskrats are valuable fur-bearers, and in some cases their flesh is used as human food. They have become quite scarce in some parts of their range because of persistent trapping. As a result, some states have established closed seasons during which it is illegal to trap muskrats. Muskrat farming is being carried on in some parts of the country.

Jack rabbits. Jack rabbits are animals of the western prairie and plains regions. They are used as food in some localities, but in other regions they either are unpalatable because of the food that they eat, or are undesirable as food because they contain internal parasites (parasitic worms). Where they are not used extensively as human food, and where their natural enemies, such as the coyotes, have been reduced in numbers, the jack rabbits may become very numerous. The writer remembers one occasion in early summer when he stopped his car in a small valley on a side road in the eastern Colorado dry lands and started to count the jack rabbits that were in sight. It was early in the morning, and both young and adult rabbits were sitting out in the bright sunlight. Probably there were two or three young rabbits to every adult. The writer counted a hundred individuals within a short distance of the car. When jack rabbits become very numerous, they are likely to invade cultivated fields and seriously damage the crops. The farmers and ranchers organize large hunting parties to carry on "rabbit drives," and in this way reduce the rabbit population.

Cottontail. The familiar cottontail rabbit is more generally sought as an object of sport. Consequently, it rarely becomes very numerous in thickly settled parts of the country. In fact some states have established closed seasons to protect the cottontails and to conserve their numbers. Like other rabbits, cottontails are plant-eaters. They sometimes chew the bark of trees in the winter when other foods are not available. In recent years the cottontails in some sections of the country have become infected with tularemia, a disease that is communicable to man.

Pig. Many of our domesticated mammals are of the large, herbivorous, hoofed type. The domesticated pig has come from the wild pigs of Asia and Europe. It is an old domestication, and has been very successful, as indicated by the fact that domesticated pigs are now raised in most parts of the world. The pig tends to be more or less omnivorous.

Sheep and goats. Domesticated sheep and goats probably have been derived from wild species of Europe and Asia. Both of these domestications are of long standing. Sheep are able to find food where some other domesticated animals would fail to do so. Goats probably are even more adaptive than sheep.

Cow. The domesticated cow represents another old domestication. The ancestors probably were wild cattle of Asia and Europe. Domesticated cattle are now found in most inhabited areas of the world.

Camels. Two species of camels belong to the domesticated group. The Bactrian camel has two "humps" on its back; the dromedary has a single "hump." Both species were domesticated at a very remote time.

Camels are not well suited to life in many parts of the world, but they are very well adapted to desert life. Accordingly, they are used extensively in the desert regions of Africa and Asia. They serve as pack and saddle animals, their milk and flesh are used as human food, and their hair is used in the manufacture of various articles.

Deer. The deer family includes many species that are utilized for their flesh and hides. The Virginia or white-tailed deer of eastern North America furnished a supply of fresh meat for the early settlers. It is a species that can be raised under protection in almost any part of the United States.

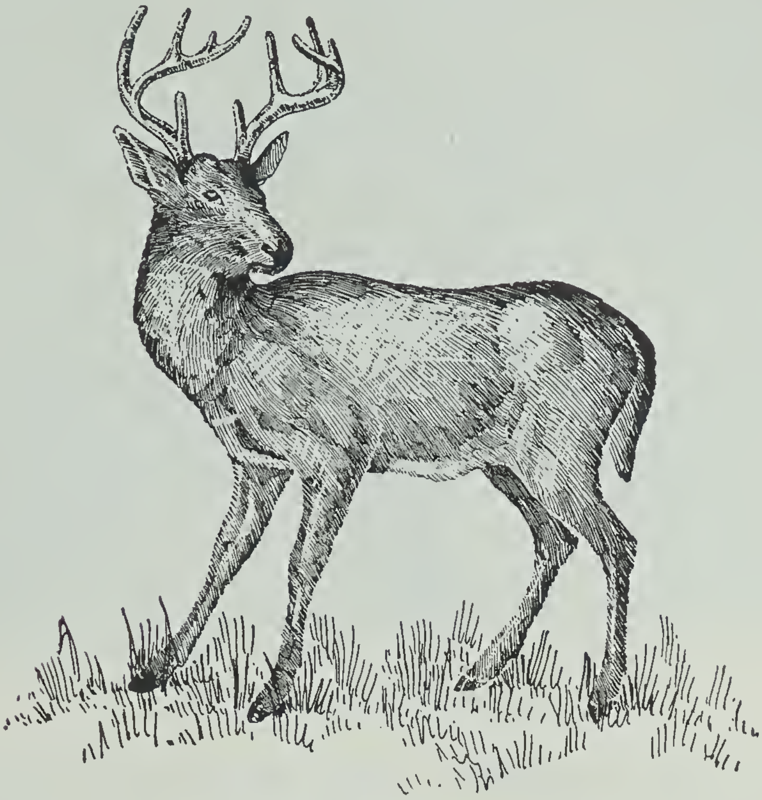
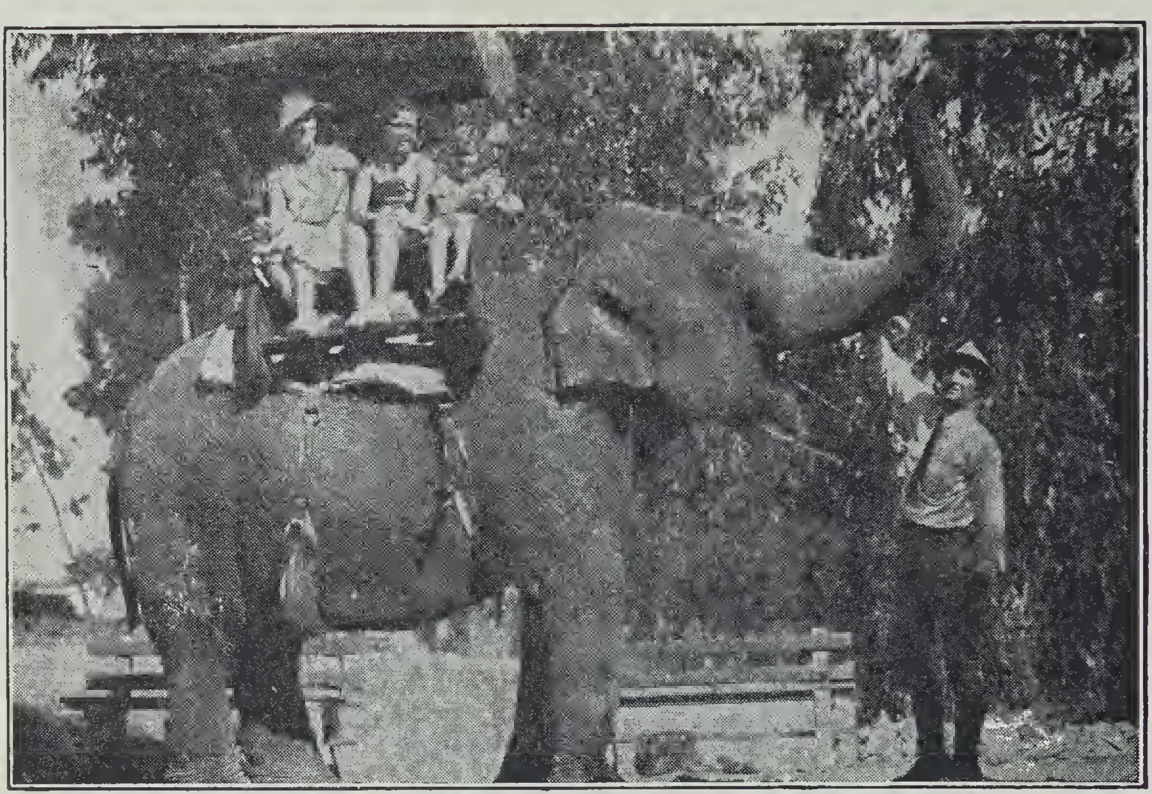


FIGURE 265. The Virginia deer.

The moose is the largest member of the deer group. Another large species is the wapiti or elk. Both of these species have become reduced in numbers, having been objects of persistent hunting. Attempts are being made to raise them under protection. Two species of caribou (sometimes called reindeer) are found in North America. These species have not been domesticated. However, a species of reindeer has been introduced into the Alaskan region from Siberia. This work was done by the United States Bureau of Education in 1892, and the Eskimos have been encouraged to raise the reindeer. The experiment appears to have been successful. At any rate, the semiwild herds have increased in numbers very rapidly. Many other species of deer are found in different parts of the world.

Horse. The horse represents an old domestication. It probably is derived from an extinct species that formerly lived in Europe and Asia. The donkey probably has been domesticated



Bransby. From Ewing Galloway, New York.

FIGURE 266. An elephant.

from a wild African ancestor. The donkey is very adaptive and can live in many regions, but is not commonly used except in places where the use of the horse is impracticable.

Elephants. The elephant group includes the Indian elephant and the African elephant. Both species develop tusks, which really are enlarged teeth. The tusks form a natural supply of ivory. Ivory hunters are said to kill 9000 to 12,000 elephants every year. The flesh is used as human food to some extent, especially the flesh of the trunks and feet. The Indian elephant is the species that has been domesticated or partly domesticated. It is used as a beast of burden, possessing enormous pushing or lifting powers. In recent years efforts have been made to domesticate the African elephant. The latter species, however, appears to be less amenable to the discipline of domesticated life.

Whales. There are two types of whales, the toothed whales and the whalebone whales. The toothed whales include the porpoises, dolphins, narwhals, sperm whales, and others. The whalebone whales do not have teeth when in the adult condition, but their mouths contain plates of whalebone. The frayed ends of these whalebone plates serve as sieves which allow water to pass through, but retain the small objects that serve as food. The sulphur-bottom whale, the finback whale, the bowhead or Greenland whale, and the humpback whale are members of the whalebone-whale group.

A number of commercial products are derived from whales. The fat of many species is boiled down to obtain the oil. Some whales sixty feet in length will yield about three hundred barrels of oil. The whalebone is used in making whips, dress stays, brushes, and other articles. A large whalebone whale may yield as much as two thousand pounds of whalebone. Some species serve as a source of supply for a special type of oil known as spermaceti. Spermaceti is used in the manufacture of candles. Ambergris is a very valuable material that has been found in the intestines of whales. It is not known how or where this substance originates. It also has been found floating on the water or washed up on the beaches. It is used in preparing medicines and perfumes.

During the nineteenth century a good many men and ships were employed in the whaling industry. As time went on, however, whales became less and less common, and other oil products made their appearance in the market. As a consequence, the whaling industry had become quite small by 1900. It has recovered somewhat since that date, but probably will never again be as important as it was in the middle of the nineteenth century.

Summary. As in the case of other animals, mammals are of importance to man for a variety of reasons. Many of our domesticated animals are mammals. They are of great importance in relation to the food supply. We obtain from them, and from various wild species, a number of commercial products, such as fur. A number of domesticated animals also are used as beasts of burden. Trapping and killing of numerous wild species has led to an alarming reduction in numbers, and this probably has stimulated the industry of fur farming. Few modern mammals are dangerous natural enemies of man, but a number of species, such as rats and mice, destroy crop plants and food products, and rats are involved in the transmission of bubonic plague.

SUGGESTED ACTIVITIES

Scientific methods

A scientist is industrious and energetic in the pursuit of his or her work.

1. If museum or school specimens are available, examine representatives of the mammal group as discussed in this chapter. Note special structures which characterize members of the various orders.
2. Prepare a table of mammals that are: (*a*) aquatic, (*b*) terrestrial, (*c*) arboreal, (*d*) aerial, and (*e*) subterranean.
3. After consulting the reading references at the end of this chapter, prepare a table of domesticated mammals, indicating in each case: (*a*) the wild ancestor, (*b*) the present distribution, and (*c*) the uses of the animal under domestication.
4. Investigate one of the following industries. Report upon the methods employed, and the economic importance of the industry: (*a*) fox farming, (*b*) rabbit raising, (*c*) whaling, (*d*) sheep raising, (*e*) cattle raising.
5. Investigate the animals used for food, for transportation, and for commercial materials in each of the following countries: Egypt, India, Japan, Italy, Alaska, Australia, China, and Chile.
6. Study the external structures, food habits, and behavior of one or more mammals which may be kept in the laboratory.

SUMMARY OF PRINCIPLES

1. Man has domesticated a number of mammals.
2. Some mammals compete with man for the food supply; a few are natural enemies.
3. Man has greatly influenced the success or failure of many species of animals.
4. Mammals serve man in a number of ways, chief among which are as food, as beasts of burden, and as a source of many raw materials for manufactured articles and clothing.
5. Some species of mammals have been greatly reduced in numbers by hunters and trappers; fur farming now is an established industry.
6. The rodents include a number of undesirable species, such as house mice, house rats, and gophers.

GUIDE QUESTIONS

1. Name three characteristics of all mammals.
2. Name five different mammals used by man for transportation purposes in various parts of the world.

3. Name six types of food obtained from mammals, and state the animals involved in each case.
4. Name five mammals which are injurious to man's interests. In each case state the harm done and the means of control.
5. Name three mammals which are in danger of extermination. Give reasons for saving these species, and suggest methods by means of which they might be preserved.
6. Name four important animals producing fibers for clothing; five which produce fur; two whose milk is used by man; and four whose hides are used for leather.
7. What are the sources and uses of spermaceti, ambergris, whalebone, and ivory?

BOOKS TO READ

Anthony, H. E. *Field Book of North American Mammals.*
Dugmore, A. R. *The Romance of the Beaver.*
DuPuy, W. A. *Our Animal Friends and Foes.*
Fitzpatrick, F. L. *The Control of Organisms.*
Hegner, R. W. *College Zoology.*
Hegner, R. W. *Parade of the Animal Kingdom.*
Hegner, R. W. *Practical Zoology.*
Henderson, J. *Economic Mammalogy.*
Palmer, E. L. *Domestic Mammals.* Cornell Rural School Leaflet, vol. 22, no. 3.
Palmer, E. L. *Larger Mammals.* Cornell Rural School Leaflet, vol. 19, no. 2.
Reese, A. M. *Outlines of Economic Zoology.*

CHAPTER XXXVIII

IMPROVEMENT OF THE RACE

Problems:

1. What are the problems of eugenics?
2. Are any mental defects inherited?
3. Are special abilities inherited?
4. Is it desirable to provide a "good" environment?

EUGENICS IS THE STUDY OF RACIAL IMPROVEMENT

Foreword. A very wealthy and prominent breeder of race horses was once overheard talking in his club in the following way. "Men and women are just like horses. You can't produce a trotting horse from a truck horse. Truck horses breed truck horses and trotting horses breed trotting horses. It's the same with human beings. Blood will tell. Education is all wrong. The public is wasting its money trying to educate people who are just truck horses."

It happens that this wealthy man was not only a breeder of fast horses but also the owner of a large mill. Here were employed thousands of immigrants — cheap labor — whose daily wage averaged perhaps one dollar per day. This man was interested in keeping labor "cheap." Education meant self-respect, a rise in the standard of living, and ultimately the ability to earn higher wages. Perhaps the man argued on the side of his purse. It was obviously an advantage to him to keep laboring people uneducated. However, he was right in saying that race horses are most often developed from racing stock.

This chance conversation involves the main questions we are concerned with in this chapter. Do the principles of heredity have any bearing upon problems of the human race? What can we expect education and good environment to do for the welfare of the race?

The study of heredity. The study of human heredity presents many difficulties. Family histories are hard to trace. The records of schools, churches, and courts throw some light upon the matter. It is, however, very hard to learn much about the character of an obscure person who died a hundred years ago. Much of our knowledge of heredity has of necessity come from the study of organisms other than man.

The student of human heredity is faced with the problem of obtaining accurate records of family histories. Among the more active organizations now at work is the Eugenics Laboratory at Cold Spring Harbor, New York. One of the contributions of this laboratory is a form of record for individual and family history.

At this laboratory plants and animals are raised through many generations. Various phases of their heredity are studied with great care. Dr. Blakeslee has studied the chromosomes of the Jimson weed, in relationship to variations of color, flower, and fruit. Visitors at the Eugenics Laboratory may see thousands of Jimson-weed plants — small plants in pots, larger plants in outdoor plots. Some are green and some are red. Some have spiny fruits and others have smooth fruits. With the aid of a microscope may be seen the different groups of chromosomes which produce these different results.

Many other institutions and individuals carry on work of similar nature. At the University of Texas, Dr. Muller has shown that X-rays produce mutations. We have previously referred to the pioneering work of Professor T. H. Morgan. He and his associates made great contributions to our knowledge of chromosomes and genes. Professor Morgan's work was considered so important that he recently (1933) was awarded the Nobel Prize.

Eugenics. Eugenics is the study of race improvement. This study was suggested by Sir Francis Galton, an English scientist, in 1883. Galton endowed a professorship for purposes of study in this field.

There has been some discussion of the problems of eugenics in the United States. Most of this discussion has related to "negative" eugenics. Negative eugenics considers ways and means of preventing mental defectives from being added to the population.

"Positive" eugenics has not yet received much public attention. Positive eugenics is the study of how to improve and conserve desirable traits. Without doubt this phase of the subject should receive increasing attention.

In 1913, the Wisconsin Marriage Law was enacted. This law required medical certification of all men who applied for marriage licenses. Since that time a number of other states have adopted similar laws. It has been found that these restrictions upon the unfit are difficult to enforce. Mental defectives do not recognize their own condition. Many of them have little sense of responsibility to society. The difficulties of legally declaring a person a mental defective are very great.

The problem is one of sociology. Do we want mentally defective persons in human society? Can we do anything to prevent increase in their number by application of what we know about heredity?

Probably most of us would answer "no" to the first question in the preceding paragraph. Let us see the extent to which hereditary factors do become involved in our social life. A thorough study has been made of several generations of families containing mental defectives, and also of some mentally superior individuals. Two such studies will be described briefly here.

The Kallikak family. It is difficult to trace family histories, particularly those in which illiteracy is the rule. One of the outstanding pieces of work of this character was done by Dr. Henry H. Goddard while he was superintendent of a school for feeble-minded at Vineland, New Jersey. The family is given the fictitious name of Kallikak (a word which means good-bad). The facts we shall relate are not fictitious. This is a story of the descendants of Martin Kallikak. He produced two distinct lines of descent. One of these lines traces the successive generations of offspring from a feeble-minded woman, the other from a normal woman. *Both* lines of descent had the *same paternal*[1] *ancestor*, who outwardly at least was of normal mentality.

Dr. Goddard began his study by investigating the relatives of a feeble-minded, seven-year-old girl sent to him for care. After painstaking research the following facts were discovered.

[1] Male.

Martin Kallikak, a soldier in the Revolutionary War, was the father of a child whose mother apparently was feeble-minded. This child, called Martin Kallikak, Jr., married, and children resulted from the union. At the time of Dr. Goddard's report, 480 descendants of Martin Kallikak and the feeble-minded woman were known to have been produced. Not all could be found for study. Of those available, 143 (21 per cent) were mental defectives. Apparently not one of these descendants exhibited exceptional ability of any kind. What an ancestry for a child! What a problem for society!

After the Revolution, Martin Kallikak married a girl of normal mentality. As a result of this marriage another line of descendants resulted. Four hundred ninety-six of this line of descendants have been traced. It appears that all of these except two were good citizens. Apparently none of them was feeble-minded.

In both of the preceding cases, the descents of Martin Kallikak lived in many different kinds of environments. The evidence suggests that heredity was a very important factor in determining whether or not they were mental defectives.

The Edwards family. Before we sum up the case for eugenics, let us examine a family of different type. This family represents the descendants of Jonathan Edwards. Jonathan Edwards was a New England clergyman of the colonial period. He came from ancestors of more than ordinary mentality, and was considered to be a profound thinker. His wife's family also was superior with regard to intelligence. Dr. A. E. Winship, formerly editor of the *New England Journal of Education*, made a study of the descendants of Jonathan Edwards.

Dr. Winship had traced 1394 descendants of Jonathan Edwards up to the year 1900. He reported the following interesting facts about these people:

1. Two hundred ninety-five were college graduates.
2. Sixty were physicians.
3. Seventy-five were officers in the army or navy.
4. More than one hundred were clergymen, or were in related activities.
5. Thirty were judges.

6. Some eighty had held public office. This group included three United States senators, and one Vice-President of the United States.
7. Sixty were authors.
8. Thirteen were college presidents.

Heredity and mentality. Here, then, we have some suggestive facts. Other data are available which point to the conclusion that certain levels of mentality are transmitted from generation to generation. Probably the quality which we call "high mentality" is the result of the structure and organization of cells in the nerve tissues. If so, this quality — good or bad — is likely to be transmitted from parent to offspring.

Of course the inheritance of mentality is infinitely more complex than the inheritance of tallness or dwarfness in peas. In the case of mentality the number of characters involved is enormously larger, and it is hard to determine what is due to heredity, and what is due to training.

It is possible, no doubt, to prevent by law the reproduction of the mentally and morally unfit. It is, moreover, justified by our present national constitution. In a recent case brought before the Supreme Court, Justice Holmes said, "Three generations of imbeciles are enough." The ruling of the Court, in substance, was that the state had the right to protect itself against harm resulting from reproduction by mental defectives.

THE INDIVIDUAL IS THE PRODUCT OF HEREDITY AND DEVELOPMENT

But who is to control the matter? Who is to decide what constitutes an undesirable defect? Of course, some defects obviously are undesirable. But somewhere a line must be drawn between the desirable and the undesirable. At the present time one of our great problems is to determine what is desirable and what is undesirable with regard to the "borderline" cases. Who is to make such a decision?

Are abilities inherited? There are other good reasons for proceeding with caution. Many desirable qualities of human beings are at least in part *acquired* — the result of education. The ability to read, to write, to speak foreign languages, to paint pictures, to play musical instruments — are these inherited as such? The evidence is against such a belief. There are probably certain inherited characters which result in the fact that one individual is better than another in learning to do these things.

Yet the possession of these desirable characters merely gives the individual the *capacity to learn or acquire* the actual skills and knowledge. It does not follow that all individuals will develop to the full extent of their abilities.

Musical ability. There are musical families and musical prodigies, but there is no case on record of children *born* with knowledge of how to play any musical instrument. In a family where music is understood and enjoyed by the parents, the children may learn something about music by imitation, or as a result of home instruction. To be successful, however, the musician must possess certain characteristics. The vocal cords of the tenor differ from those of the bass. Some people are very sensitive to slight differences in pitch. Others are much less sensitive to such differences. These, and other factors not mentioned here, are involved in musical ability. It would appear that some of these factors are largely determined by heredity.

Euthenics. The term euthenics refers to all efforts to provide the most favorable sort of environment. It is based on a belief that the life of the individual can be improved by improving the environment. Probably no one disputes this principle. Our study of biology has convinced us that all organisms — man included — respond to their surroundings.

From personal hygiene to forest conservation we may bring examples of improvement of life through improvement of environment. The public school has greatly reduced illiteracy in this country. The control of disease by methods of sanitation has unquestionably improved human surroundings. Knowledge of nutrition and other principles of health has resulted in a decline in the death rate, and a longer average span of life.

Man has learned many things about his environment. He has learned to control certain phases of the environment. He has improved many species of cultivated plants and domesticated animals. Some physical factors of the environment have been brought under control, at least in part. Man has "harnessed" the waterfalls and electricity. He has used various forms of energy to suit his needs. These achievements are important factors in what we call "civilization."

Eugenics and euthenics. There is an old controversy in which the question has been, "Which is the more important factor in human life, heredity or environment?" Some assert that heredity is more important, and there is much evidence to the effect that heredity is exceedingly important in determining what the individual may be. Other people have seen the great changes in children and adults resulting from proper nutrition and hygiene. They have observed favorable results of housing improvement in our slums. Or they have witnessed the education of savages. Some of these people are inclined to assign greater importance to favorable environment. Thus we come to have two schools of thought.

The truth probably lies between these extremes. Everyone is born with a body which has a certain capacity for development. Education and training — environment — can bring about changes. Regardless of what the heredity may be, a good environment is desirable; for a good environment, including training, will produce a more desirable result than will a bad environment.

We should recognize the fact, however, that heredity places limits upon development. In some individuals certain abilities or capacities are limited by heredity. The person who inherits color-blindness remains color-blind. If the tissue of the nervous system, as apparently determined by heredity, is of a certain kind, it may not be sensitive to experiences. In such case memory and delayed responses do not function well. There is little that can be done to improve such *capacities*. Feeble-minded persons, imbeciles, and idiots remain limited in their abilities to profit from experiences. The nature of the germ plasm limits the development of the individual, even in the best environment.

Success in life. Our conclusion must be, then, that both heredity and environment are important factors in success. Both must be considered in a program of betterment for the human race. It is futile to ask what percentage of success is determined by environment, and what percentage by heredity.

We have a certain capacity for growth and development. Our task is to make the most of it. The individual is the product of both heredity and development. Development is influenced by environment. Few people have developed many of their capacities to the full extent of their possibilities. Both mentally and physically we have a lifelong problem of developing those capacities with which we are endowed.

Man occupies a place of dominance over other organisms. This position is chiefly due to the fact that man has a greatly superior nervous system. Man is able to direct his own responses. He is conscious of his own development, and can look forward into the future. He has an understanding of the law of cause and effect and can see that the future will be a result of the present. There is evidence that this understanding of biological and other scientific principles will guide man into a larger and increasingly happy existence.

Thomas Huxley, one of the world's great biologists, summed up this point of view in the following statement:[1] "The whole of modern thought is steeped in science.... I believe that the greatest intellectual revolution mankind has yet seen is now taking place by her agency. She [science] is teaching the world that the ultimate court of appeal is observation and experiment and not authority."

SUGGESTED ACTIVITIES

Scientific methods

A scientist is alert and alive to truth, not complacent; and at all times open-minded.

1. After consulting the reading references at the end of this chapter, report upon the inheritance of some human character.
2. After consulting the reading references at the end of this chapter, report upon the "Jukes" family. Correlate this example with the history of the Kallikak family.
3. Investigate as to the number of feeble-minded persons in the United

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[1] Huxley, T. H. *Lay Sermons, Addresses, and Reviews.* D. Appleton, 1910.

States. Note the number of such people in institutions, and the cost of maintenance. (Refer to *Being Well Born*, by M. F. Guyer.)

4. Prepare a report upon one of the following current social influences (refer to readings): (*a*) immigration laws, (*b*) compulsory education, (*c*) child-labor laws, and (*d*) the use of alcohol. In each case discuss probable effects upon future generations.
5. Discuss in class the question of the inheritance of acquired characters. Report upon the experiments of Weismann and others. (See references.)
6. After consulting the reading references at the end of this chapter, prepare a report upon the mental status of: (*a*) the moron, (*b*) the feeble-minded person, (*c*) the imbecile, and (*d*) the idiot.

SUMMARY OF PRINCIPLES

1. The principles of heredity apply to human beings as well as to other organisms.
2. The problems involved in eugenics are far-reaching, and many of them remain unsolved.
3. Positive eugenics refers to attempts to improve the race by the intermarriage of persons possessing desirable traits of character.
4. Negative eugenics refers to attempts to prevent the production of mentally or physically unfit children.
5. There are evidences which indicate that certain mental defects are inherited.
6. Few individuals develop their mental or physical capacities to the fullest extent.
7. Euthenics is the science of providing a favorable environment.
8. Both heredity and environment are important factors in the development of the individual.

GUIDE QUESTIONS

1. Discuss one way in which mutations have been produced in the laboratory.
2. Define "eugenics" and "euthenics."
3. Discuss the history of the Kallikak family.
4. What principles of biology are illustrated by this family history?
5. Discuss the history of the Jonathan Edwards family.
6. What are some obstacles to the program of eugenics?
7. What are the two general factors that determine a person's character and success?

8. Are most capacities developed to the fullest extent?
9. In what ways has man improved his environment?
10. What appear to be the reasons for man's successful dominance in the world?

BOOKS TO READ

Castle, W. E. *Genetics and Eugenics.*
Downing, E. R. *Elementary Eugenics.*
East, E. M. *Heredity and Human Affairs.*
Guyer, M. F. *Being Well Born.*
Holmes, S. J. *Human Genetics and its Social Import.*
Jennings, H. S. *The Biological Basis of Human Nature.*
Morgan, T. H. *The Physical Basis of Heredity.*
Walter, H. E. *Genetics.*

REFERENCE LIBRARY IN BIOLOGY

THE following list of books is suggested for those schools or classes that wish to have available a few reference books for additional reading.

Burlingame, L. L., and others. *General Biology.*
Chamberlain, C. J. *Elements of Plant Science.*
De Kruif, Paul. *Microbe Hunters.*
Downing, E. R. *Our Living World.*
Gager, C. S. *General Botany.*
Haggard, H. W. *The Science of Health and Disease.*
Hegner, R. W. *College Zoology.*
Hegner, R. W. *Practical Zoology.*
Jennings, H. S. *The Biological Basis of Human Nature.*
McDougall, W. B. *Plant Ecology.*
Newman, H. H. *Outlines of General Zoology.*
Pearse, A. S. *Environment and Life.*
Plunkett, C. F. *Outlines of Modern Biology.*
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GLOSSARY

Ab-do′men (ăb-dō′mĕn). In man, the portion of the body cavity below the diaphragm. Also refers to the posterior region of an insect's body.

Ac-quired′ char′ac-ter (ă-kwīrd′ kăr′ăk-tẽr). A variation that has its origin in the somatoplasm; a change in the somatic cells brought about by conditions of the environment.

Ad′ap-ta′tion (ăd′ăp-tā′shŭn). A structure or behaviorism which tends to adjust the organism to its environment. The process of making adjustments in behavior or structure is also known as adaptation.

Ad′e-noids (ăd′ē-noidz). Abnormally large masses of lymphoid tissue in the upper, back part of the human throat.

Ad-re′nal glands (ăd-rē′năl glăndz). Ductless glands attached to the kidneys (man).

A-e′ri-al (ā-ȩr′ĭ-ăl). Refers to animals that fly.

Af′fer-ent im′pulse (ăf′ẽr-ĕnt ĭm′pŭls). Nerve impulse passing toward the central system.

Al′ga (ăl′gȧ). Member of a group of simple, chlorophyll-bearing plants, belonging to the Division Thallophyta.

A-mi′no ac′id (ă-mē′nō ăs′ĭd). A component part of protein.

Am-phib′i-an (ăm-fĭb′ĭ-ăn). Member of the Class Amphibia.

Am′y-lop′sin (ăm′ĭ-lŏp′sĭn). Enzyme of the pancreas which acts upon carbohydrates (man).

A-nab′o-lism (ȧ-năb′ŏlĭz′m). The building-up phase of metabolism.

A-nat′o-my (ȧ-năt′ŏ-mĭ). The study of the structure of plants and animals.

A-ne′mi-a (ȧ-nē′mĭ-ȧ). Condition in which the number of red corpuscles is below normal, or the blood lacks a normal content of hemoglobin.

An′gi-o-sperm′ (ăn′jĭ-ō-spûrm′). A seed plant, belonging to the Angiospermæ (covered seeds); one type of spermatophyte.

An′nu-al (ăn′ū-ăl). Plant that completes its life cycle in one year.

An-te′ri-or (ăn-tȩr′ĭ-ẽr). The front or head end of an animal.

An′ther (ăn′thẽr). Portion of a stamen that bears the pollen.

An′ther-id′i-um (ăn′thẽr-ĭd′ĭ-ŭm). Plant sex organ which produces male gametes.

An′ti-sep′tic (ăn′tĭ-sĕp′tĭk). Substance which inhibits the growth of microbes.

An′ti-tox′in (ăn′tĭ-tŏk′sĭn). Neutralizes the effects of a toxin.

A′phids (ā′fĭdz). Certain small insects of the bug group (Order Hemiptera).

Ap-pen′di-ci′tis (ȧ-pĕn′dĭ-sī′tĭs). Disease associated with an infected condition of the appendix (man).

A-quat′ic (ȧ-kwăt′ĭk). Refers to organisms which live in water.

Ar-bo′re-al (är-bō′rē-ăl). Refers to organisms which live in trees.

Ar′che-go′ni-um (är′kē-gō′nĭ-ŭm). Plant sex organ which produces female gametes.

Ar′ter-y (är′tẽr-ĭ). Blood vessel which conveys blood away from the heart.

A-sex′u-al (ā-sĕk′sho͝o-ăl). Without sex.

As-sim′i-la′tion (ă-sĭm′ĭ-lā′shŭn). The process by means of which digested food is incorporated in the cell and becomes a part of protoplasm.

Au′ri-cle (ô′rĭ-k'l). Chamber of heart which receives incoming blood (man).

Bac-te′ri-um (băk-tē′rĭ-ŭm). Member of a group of small (microscopic), one-celled organisms which do not contain chlorophyll. Usually classified as being simple plants.

Bar′ri-er (băr′ĭ-ẽr). An obstacle to the dispersal of a species, such as an ocean in the case of some species.

Bee′tle (bē′t'l). Any insect belonging to the Order Coleoptera.

Ber′i-ber′i (bĕr′i-bĕr′i). A deficiency disease with which the absence of vitamin B has been associated.

Bi-en′ni-al (bī-ĕn′ĭ-ăl). Plant whose life cycle embraces two years.

Bile (bīl). A secretion of the liver (in vertebrates).

Bi-ol′o-gy (bī-ŏl′ō-jĭ). The study of life.

Bird (bûrd). A feathered vertebrate.

Bi′valve (bī′välv). A mollusk having a shell of two similar valves.

Blas′tu-la (blăs′tū-lȧ). Stage in development; the cells are arranged in one layer so as to produce the effect of a hollow sphere.

Blood ves′sel (blŭd vĕs″l). A vessel of the circulatory system.

Bot′a-ny (bŏt′ȧ-nĭ). The study of plants.

Breath′ing (brēth′ĭng). The process of inhaling and exhaling air, as in the case of man.

Bron′chi-al tubes (brŏng′kĭ-ăl tūbz). Structures of the respiratory system which extend from the trachea to the lungs (man).

Ca′lyx (kā′lĭks). Outer group of modified leaves (sepals) in the complete flower.

Cam′bi-um (kăm′bĭ-ŭm). An actively growing layer of the root or stem in the higher plant.

Cap′il-lar′y (kăp′ĭ-lĕr′ĭ). Small blood vessel, connecting the end branches of an artery with those of a vein.

Car′bo-hy′drate (kär′bō-hī′drāt). A compound of protoplasm containing carbon, hydrogen, and oxygen, the latter two elements usually in the ratio of H_2O, as in sugar or starch.

Car′di-ac mus′cle (kär′dĭ-ăk mŭs′′l). Special type of muscle found in the wall of the heart.

Car′ni-vore (kär′nĭ-vōr). Member of the Class Mammalia, Order Carnivora.

Car-niv′o-rous (kär-nĭv′ō̇-rŭs). Flesh-eating.

Cell mem′brane (sĕl mĕm′brān). The retaining membrane around the cytoplasm of a cell.

Cell wall (sĕl wôl). Lifeless covering outside of the cell membrane.

Cer′e-bel′lum (sĕr′ē̇-bĕl′ŭm). A region of the vertebrate brain.

Cer′e-brum (sĕr′ē̇-brŭm). A region of the vertebrate brain.

Chlo-ren′chy-ma cells (klō̇-rĕng′kĭ-mȧ sĕlz). Cells which make up the tissues which contain chlorophyll in higher plants.

Chlo′ro-phyll (klō′rō̇-fĭl). Green-colored substance of the green plant cell, associated with the manufacture of food.

Chlo′ro-plas′tid (klō′rō̇-plăs′tĭd). Structure of the green plant cell which contains chlorophyll.

Chol′er-a (kŏl′ẽr-ȧ). Certain severe digestive disorders, such as Asiatic cholera.

Chro′ma-tin (krō′mȧ-tĭn). Granular bodies of the nuclei of cells; concerned in heredity.

Chro′mo-somes (krō′mō̇-sōmz). Structures found in the nuclei of plant and animal cells. They contain the genes, which are involved in the processes of heredity. The material of chromosomes and chromatin is the same.

Cil′i-a (sĭl′ĭ-ȧ). Short, hairlike projections of the cytoplasm, as in Paramecium.

Cleav′age (klēv′ĭj). Successive divisions of the fertilized ovum to the blastula stage.

Club moss (klŭb mŏs). A type of plant belonging to the Division Pteridophyta.

Cold′-blood′ed (kōld′-blŭd′ĕd). The body temperature varies in keeping with variations in the temperature of the environment (animal).

Con-gen′i-tal var′i-a′tion (kŏn-jĕn′ĭ-tăl vâ′ĭ-ā′shŭn). A variation which is present at the time of birth or hatching. Such a variation may be germinal or acquired.

Con′-ju-ga′tion (kŏn′jo͝o-gā′shŭn). Exchange or fusion of nuclear material of two individuals or cells, as in Paramecium.

Con-trac′tile vac′u-ole (kŏn-trăk′tĭl văk′ū̇-ōl). A structure of the cell, concerned in the elimination of liquids.

Co-rol′la (kō̇-rŏl′ȧ). Consists of petals (complete flower) that lie within the calyx.

Cor′tex (kôr′tĕks). In higher plants, the region of root and stem between the outer and central cylinders; in animals, the outer portions of various organs.

Cot′y-le′don (kŏt′ĭ-lē′dŭn). A seed leaf of a plant embryo. Also the part of the seed in which food is stored.

Cra′ni-al nerve (krā′nĭ-ăl nûrv). Nerve arising from the brain.

Cre′tin-ism (krē′tĭn-ĭz′m). An abnormal condition associated with failure of the thyroid gland early in life.

Cul′ture (kŭl′tūr). Bacteria, or other microorganisms, together with the medium in which they are grown.

Cys′ti-cer′ci (sĭs′tĭ-sûr′sī). Encysted, parasitic worms.

Cy′to-plasm (sī′tō-plăz′m). Outer area of a cell, as distinguished from the nucleus.

Derm′is (dûr′mĭs). The inner layer of the skin (man).

Di′a-be′tes (dī′ȧ-bē′tēz). Disease involving failure of the pancreas (islands of Langerhans) to produce a normal amount of insulin.

Di′a-phragm (dī′ȧ-frăm). A muscular structure which separates the thorax from the abdomen (mammals).

Di-ges′tive gland (dĭ-jĕs′tĭv glănd). A gland which secretes digestive enzymes.

Di′no-saur (dī′nō-sôr). A reptile type, now extinct.

Dom′i-nant (dŏm′ĭ-nănt). In genetics, a character which suppresses a contrasting or opposing character.

Dor′man-cy (dôr′măn-sĭ). A state of inaction characteristic of seeds before germination.

Dor′sal (dôr′săl). Upper surface of the body of an organism.

Dor′sal a-or′ta (dôr′săl â-ôr′tȧ). Large artery, lying in the middorsal region.

Drone (drōn). Male honeybee.

Du′o-de′num (dū′ō-dē′nŭm). A region of the small intestine, as in the frog, connected at its proximal end to the stomach.

E-col′o-gy (ê-kŏl′ō-jĭ). Study of the environmental relationships of organisms.

Ec′to-derm (ĕk′tō-dûrm). The outer primary germ layer of cells. The outer layer of cells in a gastrula, or in Hydra.

Ef′fer-ent im′pulse (ĕf′ẽr-ĕnt ĭm′pŭls). Nerve impulse going away from the central system.

Em′bry-o (ĕm′brĭ-ō). A developing organism.

Em′bry-ol′o-gy (ĕm′brĭ-ŏl′ō-jĭ). The study of the development of embryos.

En′do-derm (ĕn′dō-dûrm). Inner primary germ layer of cells. The inner layer of cells in a gastrula, or in Hydra.

En-vi′ron-ment (ĕn-vī′rŭn-mĕnt). The things, conditions, forces, and influences surrounding an organism.

En′zyme (ĕn′zīm). A chemical agent secreted by the organism.

Ep′i-cot′yl (ĕp′ĭ-kŏt′ĭl). Structure (bud) of the plant embryo.

Ep′i-dem′ic dis-ease′ (ĕp′ĭ-dĕm′ĭk dĭ-zēz′). One which becomes common and widespread in a given region.

Ep′i-neph′rine (ĕp′ĭ-nĕf′rĭn). A hormone secreted by medulla of an adrenal gland. Also known as adrenalin, adrenin, and suprarenin.

E-rep′sin (ē-rĕp′sĭn). Enzyme of the intestinal fluid; acts upon proteins (man).

E-ro′sion (ē-rō′zhŭn). The wearing away of land areas through the combined action of running water, freezing and thawing, and other forces.

Fat (făt). A compound found in protoplasm; contains C, H, and O.

Fau′na (fô′nȧ). The animal population of a region.

Fer′men-ta′tion (fûr′mĕn-tā′shŭn). Changing of organic substances through the agency of enzymes or ferments. Some bacteria and yeasts break down sugars, releasing carbon dioxide, water, and alcohol in this process.

Fer′ti-li-za′tion (fûr′tĭ-lĭ-zā′shŭn). The union of a mature ovum and a mature sperm.

Fla-gel′lum (flȧ-jĕl′ŭm). A long, whiplike projection of the cytoplasm, involved in the locomotion of some cells.

Flat′worm (flăt′wûrm). A member of the Phylum Platyhelminthes.

Flo′ra (flō′rȧ). Plant population of a region.

Fluke (flo͞ok). A type of flatworm.

Food vac′u-ole (fo͞od văk′ū-ōl). A food particle, in the process of being digested within the cell.

Fos′sil (fŏs′ĭl). An evidence of past life preserved in the rocks.

Fruit (fro͞ot). The ripened ovary and related structures.

Fu′mi-ga′tion (fū′mĭ-gā′shŭn). The use of poison gas to destroy insect pests or other injurious organisms.

Fun′gus (fŭng′gŭs). A type of plant belonging to the Division Thallophyta, and the Series Fungi. Fungi do not contain chlorophyll, and include such plants as mushrooms, yeasts, molds, mildews, and rusts.

Gam′ete (găm′ēt). A mature sex cell.

Ga-me′to-phyte (gȧ-mē′tō-fīt). A plant generation which bears gametes.

Gan′gli-on (găn′glĭ-ŏn). A group of nerve cells.

Gas′tric gland (găs′trĭk glănd). A gland of the stomach.

Gas′tric juice (găs′trĭk jo͞os). The secretion of a gastric gland.

Gas′tric li′pase (găs′trĭk lī′pās). Enzyme of the gastric glands; acts upon fats (man).

Gas′trin (găs′trĭn). A hormone which stimulates secretion by the gastric glands (man). This hormone is secreted by cells in the pyloric region of the stomach.

Gas′tru-la (găs′tro͞o-lȧ). A stage in development (animals). The cells are arranged in two layers, the ectoderm and the endoderm.

Gene (jēn). The hereditary unit of the chromosome.

Ge-net′ics (jē-nĕt′ĭks). The study of heredity.

Germ (jûrm). A microbe. A disease-producing organism.

Ger′mi-nal char′ac-ter (jûr′mĭ-năl kăr′ăk-tẽr). As here used, a character or variation originally due to a modification of the sex cells.

Ger′mi-na′tion (jûr′mĭ-nā′shŭn). The beginning of growth (sprouting) of a seed.

Germ plasm (jûrm plaz′m). The sex cells.

Gill (gĭl). A respiratory structure for obtaining oxygen from water, as in the amphioxus, or the frog tadpole.

Gill slit (gĭl slĭt). An opening in the wall of the pharynx.

Gland (glănd). A group of cells which produce a secretion.

Glot′tis (glŏt′ĭs). The opening connecting the pharynx with the larynx, as in man.

Gly′co-gen (glī′kō-jĕn). A storage form of starch in the liver, the muscles, and other tissues (vertebrates).

Go′pher (gō′fẽr). One type of rodent.

Graft (grȧft). As here used, a branch of a plant which is attached (grafted) to a branch of another plant.

Guard cells (gärd sĕlz). Cells which surround the stomata of leaves.

Hab′it (hăb′ĭt). A learned reaction which has become so definite that a higher center does not delay the response.

Hab′i-tat (hăb′ĭ-tăt). The place where an organism is commonly found.

He′mo-glo′bin (hē′mō-glō′bĭn). Red-colored compound, which has a strong affinity for oxygen. Found in the blood of many animals.

Her-biv′o-rous (hûr-bĭv′ō-rŭs). Refers to animals which eat plant materials for the most part.

He-red′i-ty (hē-rĕd′ĭ-tĭ). A process which involves the transmission of characteristics from parents to offspring.

Hi′ber-na′tion (hī′bẽr-nā′shŭn). A period of dormancy during cold weather, accompanied by certain changes in metabolism.

Ho-mol′o-gy (hō-mŏl′ō-jĭ). Likeness in structure; likeness in origin.

Hook′worm′ (ho͝ok′wûrm′). One of the parasitic roundworms.

Hor′mone (hôr′mōn). A chemical agent usually secreted by a ductless gland.

Horse′tail′ (hôrs′tāl′). A type of plant belonging to the Division Pteridophyta.

Hor′ti-cul′ture (hôr′tĭ-kŭl′tûr). The study of cultivated plants.

Host (hōst). An organism which supports a parasite.

Hy'brid (hī'brĭd). The offspring of two parents who differ with respect to the character in question.

Hy'pha (hī'fȧ). A unit of the vegetative portion of most fungi.

Hy'po-cot'yl (hī'pō-kŏt'ĭl). Structure (young root) of a plant embryo.

Il'e-um (ĭl'ē-ŭm). Posterior region of the small intestine, as in a frog.

Im-mune' (ĭ-mūn'). Not susceptible to a given disease.

In-fec'tious (ĭn-fĕk'shŭs). Capable of being communicated, as a germ disease.

In-oc'u-la'tion (ĭn-ŏk'ū-lā'shŭn). As here used, the introduction of a virus to develop a mild form of the disease, and future immunity.

In'stinct (ĭn'stĭngkt). Complex behavior, involving one or more reflexes, which appears as a response to a stimulus which is presented for the first time; a type of reflex.

In-tes'ti-nal flu'id (ĭn-tĕs'tĭ-năl flo͞o'ĭd). Digestive secretion of glands in the wall of the intestine.

In-tes'tine (ĭn-tĕs'tĭn). A portion of the digestive system between the stomach and the anus.

In-ver'te-brate (ĭn-vûr'tē-brāt). An animal which does not possess a backbone.

Ir'ri-ta-bil'i-ty (ĭr'ĭ-tȧ-bĭl'ĭ-tĭ). The capacity for being sensitive.

I'so-la'tion (ī'sō-lā'shŭn). The separation of a group of individuals from the rest of the species.

Ka-tab'o-lism (kȧ-tăb'ō-lĭz'm). The breaking-down phase of metabolism.

Kid'ney (kĭd'nĭ). An organ of excretion in vertebrates.

Lac'tase (lăk'tās). Enzyme of the intestinal fluid; acts upon carbohydrates (man).

Lac'te-als (lăk'tē-ălz). Lymph vessels in the region of the intestine (man).

Large in-tes'tine. Posterior region of the vertebrate intestine.

Lar'va (lär'vȧ). Among insects, the young from the time of hatching until the pupa is formed. Also used in reference to the young of other animals.

Lar'ynx (lăr'ĭngks). A respiratory structure of some vertebrates. In man, the vocal cords are located in the larynx.

La'tex (lā'tĕks). Milky fluid obtained from the rubber tree; source of rubber.

Li'chen (lī'kĕn). Type of plant which represents the symbiotic association of an alga and a fungus.

Life cy'cle (līf sī'k'l). Course of an organism's life.

Li'pase (lī'pās). Enzyme of the pancreas; acts upon fats (man).

Liv′er (lĭv′ẽr). Glandular organ associated with the digestive system in some animals.

Liv′er-wort′ (lĭv′ẽr-wûrt′). A type of plant belonging to the Division Bryophyta.

Liz′ard (lĭz′ẽrd). One type of reptile.

Lung (lŭng). Respiratory organ found in higher vertebrates.

Ly′co-pod (lī′kō-pŏd). A type of plant belong to the Division Pteriodophyta.

Lymph (lĭmf). A body fluid derived from blood plasma (man).

Lym-phat′ic sys′tem (lĭm-făt′ĭk sĭs′tĕm). System of lymph vessels developed by some vertebrates.

Malt′ase (môl′tās). Enzyme of the intestinal fluid; acts upon carbohydrates (man).

Mam′mal (măm′ăl). A haired vertebrate.

Ma-rine′ (mȧ-rēn′). Refers to organisms which live in the sea, or on its shores.

Mar-su′pi-al pouch (mär-sū′pĭ-ăl pouch). Structure for the protection of the young; developed by kangaroos and related animals.

Mat′u-ra′tion (măt͜ū-rā′shŭn). A stage in the development of a sex cell which involves the "reduction division" of the chromosomes.

Me-dul′la (mē-dŭl′ȧ). A region of the vertebrate brain. Also used in reference to the internal region of an adrenal gland.

Mem′o-ry (mĕm′ō-rĭ). A response which is retained by the nervous system.

Mes′o-derm (mĕs′ō-dûrm). The middle primary germ layer, or group of cells, as developed in Planaria or an earthworm.

Me-tab′o-lism (mĕ-tăb′ō-lĭz′m). The sum of all of the processes that function within an organism.

Met′a-mor′pho-sis (mĕt′ȧ-môr′fō-sĭs). Transformation or change, as in insect development.

Met′a-zo′a (mĕt′ȧ-zō′ȧ). Many-celled animals.

Mi′crobe (mī′krōb). A microscopic organism associated with the production of disease. A germ.

Mi-gra′tion (mī-grā′shŭn). Periodic or seasonal journeys performed by many birds, salmon, and other animals.

Mim′ic-ry (mĭm′ĭk-rĭ). As here used, the resemblance of an organism to other organisms or objects, in form as well as coloration.

Mi-to′sis (mĭ-tō′sĭs). A type of nuclear division involving complex behavior of the chromosomes.

Mol′lusk (mŏl′ŭsk). An animal belonging to the Phylum Mollusca. This group includes clams, snails, slugs, squids, octopods, etc.

Mush′rooms (mŭsh′rōōmz). Certain types of fungi.

Mu-ta′tion (mū-tā′shŭn). According to DeVries, a large inheritable variation. Now used in referring to any inheritable variation.

My-ce′li-um (mī-sē′lĭ-ŭm). Vegetative filaments (hyphæ) developed by fungi.

Nerve (nûrv). A group of nerve fibers held together by connective tissue.

Nerve cord. A central control of the nervous system as in the amphioxus.

Nerve fi′ber. An elongated process of a nerve cell.

Ni′tro-gen cy′cle (nī′trō̇-jĕn sī′k’l). Series of events in which nitrogen of the air becomes a part of plants and animals, and is returned to the air again.

Ni′tro-gen-fix′ing bac-te′ri-a (nī′trō̇-jĕn-fĭks′ĭng băk-tēr′ĭ-ȧ). Bacteria which combine free nitrogen with other elements to form compounds.

Nu′cle-us (nū′klē̇-ŭs). The dense, inner structure of a cell, as distinguished from the cytoplasm.

Œ-soph′a-gus (ē̇-sŏf′ȧ-gŭs). A region of the digestive system, distal to the mouth and pharynx. In man, the œsophagus connects the pharynx with the stomach.

Om-niv′o-rous (ŏm-nĭv′ō̇-rŭs). Eats both flesh and plant materials; usually it is implied that many different kinds of foods are eaten.

Or′gan (ôr′găn). A group of tissues performing a definite function.

Or′gan-ism (ôr′găn-ĭz’m). Any living thing.

O′va-ry (ō′vȧ-rĭ). A female sex organ.

O′vi-duct (ō′vĭ-dŭkt). A female structure which conveys the eggs to the exterior, as in the frog.

O-vip′a-rous (ō̇-vĭp′ȧ-rŭs). Refers to animals which lay eggs.

O′vum (ō′vŭm). A female sex cell.

Pan′cre-as (păn′krē̇-ăs). A glandular organ associated with the digestive system (frog, man).

Par′a-site (păr′ȧ-sīt). An organism which lives at the expense of another organism.

Par′a-thy′roids (păr′ȧ-thī′roidz). Glandular structures of vertebrates; located in the neck region.

Pas′teur-i-za′tion (păs′tẽr-ĭ-zā′shŭn). Heating a fluid sufficiently to kill most of the microbes it may contain.

Pep′sin (pĕp′sĭn). An enzyme of the gastric juice; acts upon proteins (man).

Per-en′ni-al (pẽr-ĕn′ĭ-ăl). A plant which lives on from year to year.

Pet′al (pĕt″l). A leaf of a corolla (flower).

Phar′ynx (făr′ĭngks). Region of digestive tract between the mouth and the œsophagus (man). The back part of the mouth cavity.

Phlo′em (flō′ĕm). Outer part of a fibrovascular bundle in a higher plant. The food-conducting tissue.

Pho'to-syn'the-sis (fō'tō̂-sĭn'thē̂-sĭs). Process by means of which the green plant manufactures carbohydrates from carbon dioxide and water, using sunlight as a source of energy.

Phys'i-ol'o-gy (fĭz'ĭ-ŏl'-jĭ). The study of function in plants and animals.

Plank'ton (plăngk'tŏn). Small organisms, living in the open water, which constitute the basic food supply for many animals.

Plas'ma (plăz'mȧ). The fluid portion of the blood.

Pol'li-na'tion (pŏl'ĭ-nā'shŭn). Process of transferring pollen from stamens to pistils.

Por'tal blood ves'sels (pōr'tăl blŭd vĕs''lz). In man these vessels collect blood in the intestinal region and convey it to the liver.

Pro-tec'tive col'or-a'tion (prō̂-tĕk'tĭv kŭl'ẽr-ā'shŭn). Coloration which renders the organism inconspicuous. Such coloration may have value in that the organism is less likely to be seen by its enemies.

Pro'te-in (prō'tē̂-ĭn). A compound of protoplasm containing C, H, O, and N.

Pro-thal'lus (prō̂-thăl'ŭs). The gametophyte of a fern.

Pro'to-plasm (prō'tō̂-plăz'm). All living material of the cell.

Pro'to-zo'a (prō'tō̂-zō'ȧ). A group of simple animals belonging to the Phylum Protozoa.

Pseu'do-po'di-um (sū'dō̂-pō'dĭ-ŭm). A fingerlike projection of the cytoplasm, as in Amœba.

Psy-chol'o-gy (sī-kŏl'ō̂-jĭ). The study of mental phenomena.

Pty'a-lin (tī'ȧ-lĭn). An enzyme of the saliva; acts upon carbohydrates (man).

Pu'pa (pū'pȧ). The stage preceding the adult stage in complete metamorphosis of insects.

Re-ces'sive (rē̂-sĕs'ĭv). Refers to a character which is suppressed by an opposing dominant character (heredity).

Red cor'pus-cle (kôr'pŭs-'l). A blood cell which contains hemoglobin (man, frog).

Re'flex ac'tion (rē'flĕks). As here used, an automatic response to stimulation, which involves the reflex arc.

Re'flex arc (ärk). The mechanism responsible for reflex acts (man).

Re-gen'er-a'tion (rē̂-jĕn'ẽr-ā'shŭn). The replacement of a lost structure or part.

Re'nal tu'bules (rē'năl tū'būlz). Tubules found in the kidneys of vertebrates.

Ren'nin (rĕn'ĭn). An enzyme of the gastric juice; acts upon proteins (man).

Re'pro-duc'tion (rē'prō̂-dŭk'shŭn). The production of new individuals.

Rep'tile (rĕp'tĭl). A chordate of the Class Reptilia.

Res'pi-ra'tion (rĕs'pĭ-rā'shŭn). The process by means of which oxygen enters the cell and carbon dioxide is removed. Respiration includes oxidation within the cell.

Ret′i-na (rĕt′ĭ-nȧ). A structure of the vertebrate eye, directly connected with the optic nerve.

Rhi′zoid (rī′zoid). A rootlike structure developed by some lower plants.

Rick′ets (rĭk′ĕts). A deficiency disease, associated with lack of vitamin D.

Rock (rŏk). Stony material forming the earth's crust.

Ro′dent (rō′dĕnt). A member of the Class Mammalia, Order Rodentia.

Root (ro͞ot). The descending axis of a plant; usually the underground portion.

Root hair (hâr). A hairlike structure of epidermal cells of a root. The root hair absorbs water and dissolved mineral materials from the soil.

Round′worm′ (round′wûrm′). A member of the Phylum Nemathelminthes. The members of this group are not segmented.

Rusts (rŭstz). Certain types of fungi.

Sal′a-man′der (săl′ȧ-măn′dẽr). One type of amphibian.

Sal′i-var′y glands (săl′ĭ-vĕr′ĭ). Glands which discharge saliva into the mouth.

Sap′ro-phyte (săp′rō-fīt). Organism which lives upon dead organic material.

Scale in′sects (skāl ĭn′sektz). Certain small insects belonging to the Order Hemiptera; scales are developed as protective coverings.

Scur′vy (skûr′vĭ). A deficiency disease, associated with the absence in the diet of vitamin C.

Se-cre′tin (sė-krē′tĭn). A hormone which stimulates secretion by the liver, pancreas, and small intestine (man).

Seg′re-ga′tion (sĕg′rē-gā′shŭn). The separation of contrasting genes during the early stages of reproduction.

Se′pal (sē′păl). A leaf of the calyx (flower).

Shrew (shro͞o). A small type of mammal belonging to the Order Insectivora.

Si′nus (sīnŭs). A space between cells or layers.

Skel′e-tal mus′cle (skĕl′ė-tăl mŭs″l). Striated type of muscle attached to the skeleton (man). The so-called "voluntary muscle."

Skull (skŭl). Skeleton of the head region in vertebrates. Includes the portion which surrounds the brain, and the bones of the facial region.

Smooth mus′cle (smo͞oth mŭs″l). An "involuntary" type of muscle (man). Commonly represented in the walls of internal organs.

Smuts (smŭtz). Certain types of fungi.

Soil (soil). Pulverized rock mixed with organic materials.

So′ma-to-plasm (sō′mȧ-tō-plăz′m). All of the cells of an organism except the sex cells.

Spe′cies (spē′shĭz). A kind of organism. A group of individuals having a common heritage.

Sperm (spûrm). Male sex cell.

Spi′nal cord (spī′năl kôrd). Part of central nervous system, extending along the vertebral column (man).

Spi′nal nerves (spī′năl nŭrvs). Nerves connecting with the spinal cord.

Spi′ro-chete (spī′rō-kēt). A member of a group of minute, spiral-shaped organisms.

Spleen (splēn). A ductless organ located in the vertebrate abdomen.

Spore (spōr). A part of an organism which develops into a new individual without being fertilized. A spore is usually a single-celled structure.

Spo′ro-phyte (spō′rō-fīt). Plant generation which is asexual. The conspicuous generation among higher plants.

Stem (stĕm). The stalk (supporting the leaves and flowers) of the plant. Thallus plants do not have stems.

Ster′i-li-za′tion (stĕr′ĭ-lĭ-zā′shŭn). Destruction of all germs in or on a substance, as, for instance, by boiling, or through the use of certain chemicals.

Stig′ma (stĭg′mȧ). A portion of the pistil (flower).

Sto′ma (stō′mȧ). A pore of plants (in epidermis), which permits the passage of gases, including water vapor.

Stom′ach (stŭm′ăk). An organ of the digestive system, found in some animals.

Sub-spe′cies (sŭb-spē′shĭz). A subdivision of a species; a variety.

Sub′ter-ra′ne-an (sŭb′tĕr-rā′nē-ăn). Refers to organisms which live *under* the ground.

Su′crase (sū′krās). Enzyme of the intestinal fluid; acts upon some carbohydrates (man).

Sym′bi-o′sis (sĭm′bī-ō′sĭs). The association of two species which live together to their mutual benefit. A lichen furnishes an example of symbiotic association.

Sym′pa-thet′ic nerv′ous sys′tem (sĭm′pȧ-thĕt′ĭk). Two chains of ganglia with branch nerves to the internal organs, as in a frog. The sympathetic nervous system controls many automatic internal activities.

Sys′tem (sĭs′tĕm). A group of associated organs, performing a definite function; such as the digestive system of a frog.

Tape′worm′ (tāp′wûrm′). One type of flatworm. Many tapeworms are internal parasites.

Tax-on′o-my (tăks-ŏn′ō-mĭ). The laws and principles of classification.

Ter′mites (tûr′mītz). Insects belonging to the Order Isoptera; sometimes called "white ants." They are not, however, true ants.

Ter-res′tri-al (tĕ-rĕs′trĭ-ăl). Refers to organisms which live *on* the ground.

Tes′tis (tĕs′tĭs). A male sex organ.

Thal′lo-phyte (thăl′ō-fīt). A plant belonging to the Division Thallophyta. A thallus plant. Such a plant has no distinct roots, stems, or leaves.

Thal′lus (thăl′ŭs). The body of a thallophyte, such as a rockweed.

Tho-rac′ic duct (thō-tăs′ĭk dŭkt). The main vessel of the lymphatic system (man).

Tho′rax (thō′răks). The upper part of the body cavity (man); the portion of the body cavity which is above the diaphragm. Among insects, the thorax is the middle portion of the body.

Thy′mus (thī′mŭs). A glandular structure of vertebrates.

Thy′roid gland (thī′roid). A ductless gland of vertebrates, located in the neck region.

Thy-rox′in (thī-rŏk′sēn). A hormone produced by the thyroid gland.

Tis′sue (tĭsh′ū). A group of similar cells forming a layer.

Ton′sils (tŏn′sĭls). A pair of lymph glands (man).

Tox′in (tŏk′sĭn). A poisonous by-product secreted by an organism.

Tra′che-a (trā′kē-ȧ). A respiratory passage which connects the larynx with the bronchial tubes (man).

Tran′spi-ra′tion (trăn′spĭ-rā′shŭn). The loss of water vapor by plants.

Tri-china (trĭ-kī′nȧ). One of the parasitic roundworms. When present in the human body it is responsible for the disease known as trichinosis.

Tro′pism (trō′pĭz′m). A characteristic or mechnical response to a particular stimulus. Usually a tropism is a response of the whole organism, or a large part of the organism.

Tryp′sin (trĭp′sĭn). An enzyme of the pancreas; acts upon proteins (man).

U′nit char′ac-ter (ū′nĭt kăr′ăk-tẽr). A character which is inherited independently, or as a unit. The inheritance of such a character may be dependent upon one or more pairs of genes.

U′re-a (ū′rē-ȧ). A waste of protein metabolism; formed largely in the liver from other waste substances (man).

U-re′ter (ū-rē′tẽr). A duct which conveys urine from a kidney to the bladder (man).

U-re′thra (ū-rē′thrȧ). A duct which conveys urine from bladder to the exterior (man).

U′rine (ū′rĭn). A secretion of the kidneys, containing wastes.

Vac′ci-na′tion (văk′sĭ-nā′shŭn). Inoculation with cowpox virus to develop immunity to smallpox. Sometimes used in referring to inoculation against other diseases.

Va′ri-a′tion (vâr′ĭ-ā′shŭn). Departure from the parental types. Also used in referring to differences which exist among members of the same species.

Vein (vān). A blood vessel which conveys blood toward the heart.

Ven′om-ous (vĕn′ŭm-ŭs). Having a poisonous secretion known as venom. Among snakes, the pit vipers serve as examples.

Ven′tral (vĕn′trăl). Refers to the lower surface of an organism.

Ven′tri-cle (vĕn′trĭ-k′l). May refer either to a chamber of the heart, or to a cavity in the brain.

Ver′te-brate (vûr′tē-brāt). An animal possessing a backbone or vertebral column.

Vil′li (vĭl′ī). Fingerlike projections on the internal surface of the small intestine (man).

Vi′ta-min (vī′tȧ-mĭn). A constituent of foods whose presence in small quantity appears to be necessary for normal metabolism in an organism.

Vi-vip′a-rous (vī-vĭp′ȧ-rŭs). Refers to animals which bear their young.

Vol′un-tar′y act (vŏl′ŭn-tĕr′ĭ ăkt). A delayed response, usually involving external stimulus and internal need; involves "thinking."

Warm′-blood′ed (wôrm′-blŭd′ĕd). The body temperature is comparatively high and fairly constant. Birds and mammals are warm-blooded.

White cor′pus-cle (hwīt kôr′pŭs-′l). A blood cell which destroys bacteria and wastes, as in a frog or man.

Work′ers (wûr′kẽrz). Members of termite, ant, or bee colonies, which do the bulk of the work necessary in their social groups.

Xy′lem (zī′lĕm). The woody part of a fibrovascular bundle; the water-conducting tissue.

Yeasts (yĕstz). Certain types of fungi.

Zo-ol′o-gy (zō̂-ŏl′ō̂-jĭ). The study of animal life.

Zy′gote (zī′gōt). A fertilized ovum; produced by the union of a sperm and an ovum.

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